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ICE STRENGTH INDEXER PHASE III

TP 10486E

for

Transportation Development Centre
Policy and Coordination Group
Transport Canada

by

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PROJECT TEAM

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Un sommaire en français de ce rapport est inclus avant la table des matières.

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16. Abstract

The ice strength Indexer is a device used to measure the mechanical properties of model ice. The Indexer was designed by Melville Shipping Ltd. in association with the Institute for Marine Dynamics and the Transportation Development Centre of Transport Canada. The Indexer consists of three instrumented plates and a water jet system. The three plates are used to break the ice in flexural, shear and crushing. A computer program has been developed that is used to analyze the force time histories from the plates and convert them to ice strength values. This report presents a description of the new Indexer configuration and a series of preliminary tests that have demonstrated that the Indexer output may be correlated with conventional manual strength measurements and confirms the validity of the Indexer concept.

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16. Résumé

L'Indexer est un dispositif de mesure de la résistance mécanique d'une glace modèle, étudié par la société Melville Shipping Ltd. en collaboration avec l'Institut de dynamique marine et le Centre de développement des transports de Transports Canada. Il se compose d'un dispositif coupe-glace à jets d'eau et de trois plaques métalliques, reliées à des capteurs dynamométriques et servant à charger la glace de manière à provoquer la rupture en flexion, en cisaillement et en écrasement. Un logiciel sert à l'analyse des courbes effort-temps enregistrées par l'Indexer, pour en déduire les valeurs de résistance de la glace. Ce rapport décrit les améliorations apportées au dispositif Indexer et présente les résultats d'essais préliminaires, qui ont permis d'établir une corrélation entre les résultats obtenus avec l'Indexer et ceux obtenus par les méthodes classiques de mesure.

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SUMMARY

Model testing in ice demands a knowledge of the mechanical properties of the model ice. The extent to which these ice mechanical properties vary and how accurately they may be defined by the experimenter is of paramount importance. Conventional methods require individual samples to be cut from the ice sheet prior to and following a model test run and tested to destruction. These methods are very time intensive and usually limited to simple in-situ cantilever beam tests for flexural strength. Other mechanical properties, such as shear and crushing strength, are assumed to be proportional to the flexural strength.

During the last five years, Melville Shipping Ltd., supported by the Transportation Development Centre (TDC) and the Institute for Marine Dynamics (IMD), have developed a tool that will measure the mechanical properties of model ice continually down the length of the model basin. There are clearly very significant advantages to such a device over conventional methods.

This report presents the results from the third phase of work to develop the device, now known as the Ice Strength Indexer, or INDEXER. The objective of this project, was to improve the utility and performance of the INDEXER developed under previous projects.

The report is divided into five main sections: a brief description of the INDEXER and its operating principles; a description of the development of more efficient manual test methods; the redesign of the INDEXER to improve overall utility and definition of the ice; a description of the software application that is used to calculate the INDEXER ice strength; and a description of the physical model tests of the INDEXER in the IMD ice tank.

The configuration of the INDEXER was designed to be simple and flexible. The design consists of four components;

a) The ice cutter: The objective of the water jet cutter is to prepare two parallel cuts in the ice. The cuts have to be made quickly with minimum disturbance to the ice.

b) The flexural plate: Behind and between the cutters is an inclined plate that is angled down into the ice. As the cutters move ahead of the inclined plate, the

ice comes into contact with the plate, is pushed down and fails in almost pure bending.

c) The shearing plate: Located on one side of the flexural plate the shearing plate is significantly narrower than the flexural plate. One edge of the shearing plate is aligned with the cutter track while the outside edge extends into the unbroken ice sheet. As the plate advances into the ice a strip of ice is sheared off.

d) The crushing plate: Located on the opposite side of the bending plate to the shearing plate. The crushing plate is angled into the uncut ice sheet. As the plate advances into the ice it crushes the edge of the cut track to a depth equal to its penetration.

The different ice thicknesses, strengths and speeds influence the configuration requirement of the INDEXER and as a result, the INDEXER has been designed to be sufficiently flexible to accommodate different plate widths, different plate angles and relative positions of the plates and cutters.

The primary objective of the INDEXER is to quickly measure the ice mechanical properties as close to the test time as possible. This is necessary due to the decay of the ice properties over time. The INDEXER addresses this by permitting the experimenter to test the model ice strength either during the model test or directly after. The time delay between the test and the model ice characterization is therefore minimized and the interpolation or extrapolation to actual test time, necessary for conventional manual testing, is avoided.

The INDEXER has been shown to have the potential to comprehensively measure the mechanical properties of the model ice with respect to the flexural, shearing and crushing modes.

The conclusions of the INDEXER project may be summarized as:

a) The ice strength output from the computer program has been compared to the manual test measurements made during the tests. The results of the comparison yield a correlation factor, or offset, which may be applied to the INDEXER output to yield representative ice strengths along the ice tank.

b) The improved functionality of the redesigned INDEXER has demonstrated that the device can be easily incorporated into the standard model testing procedure adopted by IMD.

c) The additional ice strength information provided by the use of the INDEXER will significantly improve the capability of model ice tank users to accurately predict the performance of ice transitting ships.

The INDEXER program is considered to be a success with significant improvement being made to both the INDEXER design, the INDEXER support platform and the testing procedure. However, there are a number of areas that are considered to require more work to fully develop the INDEXER concept. These may be summarized as follows.

a) Although a series of tests was conducted on the INDEXER, it was not sufficient to fully develop the relationship between the strength correlation factor and the INDEXER speed, ice thickness and ice strength. It is considered that a series of additional tests is required to improve this correlation.

b) Although a sophisticated data analysis program has been developed to analyze the INDEXER output data, the current data acquisition system on the IMD ice tank carriage does not permit this analysis to be done immediately on the carriage. An integrated data acquisition system and automatic data analysis system would permit a more direct analysis of the model ice strength on the carriage.

c) The current deployment of the INDEXER is manual using a hand cranked jack and manually deployed back stays. Realistically, if the unit is to be used by the tank personnel on a regular basis it must be capable of being deployed automatically. This can be achieved simply using a remote control system based on the computer. A total INDEXER system would include an automatic deployment of the INDEXER to the prescribed height, a data collection system and an integrated data analysis system.

d) The primary objective of the INDEXER is to measure the mechanical properties of model ice to permit the accurate performance prediction of icebreaking ships. The procedure currently used to correct the model ice mechanical strength to full scale is based on the flexural strength. However it is well known that the shear and crushing strength of the ice also have an influence on model hull resistance. A method must be developed therefore to establish the relationship between the shearing and crushing strength of model ice and the resistance. Based on this relationship, it will be possible to correct model resistance for these strength properties in addition to the flexural strength.

SOMMAIRE

Les essais sur modèles réduits de cargos brise-glace reposent de toute évidence sur la connaissance des caractéristiques mécaniques de la glace modèle. Il est très important que les variations de ces dernières à l'échelle du bassin, ainsi que l'exactitude des méthodes de mesure utilisées soient connues. Les méthodes utilisées jusqu'ici pour déterminer les paramètres de résistance des glaces modèles sont laborieuses: il faut, avant et après chaque essai sur modèle réduit, prélever des échantillons de la glace et les soumettre aux essais de résistance voulus jusqu'à la rupture. Le plus souvent, seule la résistance à la rupture en flexion est mesurée in situ, par la méthode de la poutre, la résistance au cisaillement et la résistance à l'écrasement, supposées proportionnelles au premier paramètre, étant déduites par calcul.

Au cours des cinq dernières années, la société Melville Shipping Ltd., appuyée par le Centre de développement des transports (CDT) et l'Institut de dynamique marine (IDM), a étudié un dispositif permettant de mesurer en continu les caractéristiques mécaniques d'une glace modèle, d'un bout à l'autre du bassin. Les avantages que procurent un tel appareil par rapport aux méthodes classiques de mesure sont incontestables.

Ce rapport présente les résultats de la troisième phase des travaux de mise au pont du dispositif, maintenant connu sous le nom de INDEXER, dont le but était de perfectionner le dispositif et d'en étendre le champ d'utilité.

Le rapport est présenté en cinq parties: description sommaire du dispositif INDEXER et de son mode de fonctionnement; description de méthodes améliorées de mesure manuelle des caractéristiques mécaniques d'une glace modèle; modifications apportées au dispositif INDEXER, en vue d'en rehausser l'efficacité et d'en étendre l'utilité; description du logiciel utilisé pour calculer les valeurs de résistance de la glace à partir des valeurs enregistrées par l'INDEXER; résultats d'essais sur glaces modèles dans le bassin de l'IMD.

Le dispositif étudié devait être simple et se prêter aux modifications qui se révéleraient nécessaires. La configuration retenue comprend les éléments suivants :

a) un dispositif coupe-glace à jets d'eau, servant à découper une bande de glace de largeur constante devant les plaques de charge; l'action des jets d'eau doit être rapide et ne doit pas perturber indûment la couche de glace environnante;

b) une plaque de flexion, placée derrière et entre les jets d'eau; elle est inclinée vers le bas, de manière à imprimer une flexion à la bande de glace découpée par les jets d'eau; l'action de la plaque de flexion en est une de flexion quasiment pure;

c) une plaque de cisaillement, considérablement moins large que la plaque de flexion, à laquelle elle est juxtaposée; le bord intérieur de la plaque de cisaillement est en alignement avec un des jets de coupage, l'autre avançant dans la couche de glace environnante et lui imprimant une force de cisaillement;

d) une plaque d'écrasement, placée de l'autre côté de la plaque de flexion; elle est inclinée de manière à écraser le bord de la couche de glace environnante sur toute sa hauteur de pénétration.

De toute évidence, le dispositif de caractérisation des glaces modèles doit être réglable en fonction de l'épaisseur et de la résistance de la glace et de la vitesse d'avancement dans le bassin. Aussi l'INDEXER se prête-t-il à divers réglages : il peut s'adapter à des plaques de charge de différentes largeurs, et l'angle d'inclinaison des plaques est réglable, ainsi que la position des plaques par rapport aux jets de coupage.

Comme les caractéristiques mécaniques d'une glace subissent des variations dans le temps, il fallait un moyen de les mesurer à un moment le plus rapproché possible des essais de résistance à l'avancement sur modèles réduits. L'INDEXER répond à ce besoin puisqu'il permet de mesurer la résistance de la glace soit au cours des essais sur modèles réduits, soit immédiatement après. Le temps séparant les essais de résistance à l'avancement et la caractérisation de la glace modèle est donc réduit au minimum, et il n'est plus nécessaire de procéder à des interpolations ou des extrapolations, comme c'est le cas avec les méthodes classiques de mesure.

Il a été démontré que l'INDEXER pourrait être un outil valable de mesure de la résistance d'une glace modèle en flexion, en cisaillement et en écrasement.

Les présents travaux ont permis de tirer les conclusions suivantes :

a) Les valeurs de résistance de la glace calculées à l'aide du modèle informatique ont été comparées aux mesures prises selon les méthodes classiques en cours d'essai, et la comparaison a permis de dégager un facteur de corrélation qui pourrait servir à corriger les données enregistrées par l'INDEXER pour obtenir des courbes de résistance représentatives d'un bout à l'autre du bassin.

b) L'INDEXER modifié, plus fonctionnel que le premier prototype, pourrait facilement être intégré à l'appareillage et aux procédés d'essai en bassin de l'IDM.

c) Les données de caractérisation obtenues grâce à l'INDEXER peuvent améliorer grandement l'exactitude des prévisions sur la performance des brise-glace en conditions réelles.

Ces derniers travaux de mise au point n'ont pas été vains, puisqu'ils ont permis d'améliorer considérablement aussi bien la configuration du dispositif de mesure et de son chariot, que les procédés d'essai. Il reste toutefois plusieurs améliorations à apporter avant que l'INDEXER ne puisse être considéré au point. Celles-ci sont brièvement décrites ci-dessous.

a) Bien que l'INDEXER ait été soumis à toute une série d'essais, ceux-ci n'ont pas été suffisants pour permettre de définir exactement la relation entre le facteur de corrélation dégagé d'une part et, d'autre part, la vitesse d'avancement de l'INDEXER, l'épaisseur de la glace et la résistance de celle-ci. Les chercheurs estiment qu'une série d'essais complémentaires seraient nécessaires pour préciser cette corrélation.

b) Un programme sophistiqué a bien été élaboré pour l'analyse des données enregistrées par l'INDEXER, mais le système de collecte de données dont est actuellement équipé le bassin de l'IDM ne permet pas de passer directement à cette analyse. Un système intégré de collecte et d'analyse des données donnerait une vue plus directe de la résistance de la glace modèle à l'avancement du chariot.

c) A l'heure actuelle, la mise en oeuvre de l'INDEXER se fait manuellement, à l'aide d'un vérin à manivelle et de haubans. Si on envisage un usage courant de l'INDEXER, il faudrait que celui-ci puisse être actionné automatiquement. Il suffirait pour cela de prévoir un dispositif de télécommande relié à l'ordinateur. Un système INDEXER complet comprendrait donc un système de commande automatique permettant de régler le dispositif à distance et un système intégré de collecte et d'analyse des données.

d) L'INDEXER a été étudié comme moyen de mesurer les caractéristiques mécaniques d'une glace modèle, dans le but ultime de pouvoir établir des prévisions exactes sur les performances réelles des brise-glace. La méthode utilisée jusqu'à ce jour pour la correction d'échelle repose uniquement sur le paramètre de résistance à la rupture en flexion. Or, on sait que la résistance de la glace au cisaillement et à l'écrasement influe également sur la résistance globale à l'avancement des brise-glace. Il faudrait donc élaborer une méthode qui permette de définir aussi l'influence de la résistance au cisaillement et à l'écrasement de la glace sur la résistance globale à l'avancement des modèles de cargos essayés. La correction d'échelle pourra alors se faire en tenant compte des trois paramètres de résistance et non plus d'un seul.

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1. INTRODUCTION

One of the most widely used methods to predict the performance of ice transitting ships is the model ice tank. These facilities usually use refrigeration systems to freeze a solution of water and some dopant to simulate, at model scale, the properties of full scale ice. The procedures and dopants that are used to create the simulated ice sheets have been well documented in the literature (Timco 1985, Baker 1985). The validity of these model tests will clearly depend to a large extent on the quality and consistency of the ice sheets and, most importantly, on the ability to measure these properties. The extent to which the ice mechanical properties vary and how accurately these can be defined by the experimenter is therefore of paramount importance.

The conventional methods used to measure the mechanical properties of ice, with the notable exception of modulus, require individual samples to be cut from the ice sheet prior to and following a model test run and tested to destruction. The modulus test is a non-destructive test conducted on a large area of the ice sheet. The conventional methods are usually limited to simple in-situ cantilever beam tests for flexural strength. The other mechanical properties, such as shear and crushing strength, are usually assumed to be proportional or in some way related to the flexural strength and are seldom or sporadically recorded.

During the last five years Melville Shipping Ltd, supported by the Transportation Development Centre (TDC) and the Institute for Marine Dynamics (IMD), has developed a tool that will measure the mechanical properties of model ice continually down the length of the model basin. There are clearly very significant advantages to such a device over conventional methods.

This report presents the results from the third phase of work to develop the device, now known as the Ice Strength Indexer, or INDEXER.

The work conducted to date may be summarized as :

Phase I: The development of the original concept and preliminary testing at the NRC Hydraulics Laboratory in Ottawa, Ontario. (Baker 1986, Baker et al. 1986).

Phase II: A report in two sections (Baker 1987);

a) The further development of the INDEXER with improve ice cutters and data analysis system.

b) A preliminary effort to develop the correction factors necessary to directly use the results of the INDEXER to correct model test results.

The objective of the third phase of the work is to improve the utility and performance of the INDEXER developed under these previous projects.

The report is divided into five main sections;

a) A brief description of the INDEXER and it's operating principles.

b) The development of more efficient manual test methods to monitor the mechanical properties of the ice using conventional methods. These may then be used for correlation with the INDEXER test results.

c) The redesign of the INDEXER to improve overall utility and definition of the ice. This component of work included; redesign and construction of the ice cutting system; redesign and construction of the plate support and force monitoring gauges; design and construction of a suitable support for the device on the IMD ice tank carriage and; upgrading of the data analysis program used to correlate the INDEXER forces to ice mechanical properties.

d) A description of the software application that is used to calculate the INDEXER ice strength and correlate this to the manual strength data.

e) The physical model tests of the INDEXER in the IMD ice tank and correlation with the manual test methods.

2. THE INDEXER CONCEPT

During the last ten years the technology with respect to the physical model testing of ship hulls in an ice environment has significantly advanced. This technology growth has included the construction of large new "Third Generation" ice tanks in Canada and Europe, the development of improved data acquisition systems, the introduction of new tank melt dopants and now a growing interest in simulating more complex ice environments. However, a significant shortfall in this technology growth is the definition of the mechanical properties of the ice itself. It is interesting to note that the large amounts of money and time are being invested in testing models in a model environment about which very little is known. Typically the experimenter testing in the Canadian ice tank in St. John's will have the following data with respect to a particular ice sheet;

a) A single Elastic Modulus, usually measured within about an hour before the test.

b) The flexural strength of the ice in five or six locations, usually measured using a hand held spring balance, or load cell, and a manually cut cantilever.

c) The thickness of the ice sheet every 2.0 m along the test track.

Clearly, the only parameter measured comprehensively is the ice thickness. The flexural strength tests are difficult to conduct with guaranteed consistency due to the potential damage to the ice caused by cutting the samples with a hand held saw and the different cutting and loading techniques used by the different technicians conducting the tests.

There is usually no effective measurement of either the crushing or shearing strength of the ice.

The impact of these shortfalls is reflected in the inconsistency of the model tests. In the past this, lack of consistency, has usually been associated with the "Stochastic" nature of model ice testing. However it is now the belief of the authors that, to a large extent, the 15 to 20% deviations in model testing results, for similar tests, is caused by the experimenter having no real appreciation of the mechanical properties of the model ice.

In order to address this shortfall, Melville Shipping Ltd invented the INDEXER concept. The objective was to measure the mechanical properties of the ice in a consistent and repeatable fashion along the entire length of the ice sheet. Three failure modes were addressed; flexural, shear and crushing.

It was soon recognised that failure does not occur uniquely in any one mode and it was accepted that the actual ice failure would only be "representative" of a particular failure mode. In other words the failure would be predominantly but not exclusively in a particular failure mode. Therefore, it was accepted that the flexural failure plate, for example, would not induce pure flexure but that there would be, inevitably, some crushing and shearing at the cantilever root.

The configuration of the INDEXER was designed to be simple and flexible. The design consists of four components as shown in Figure 2.1.

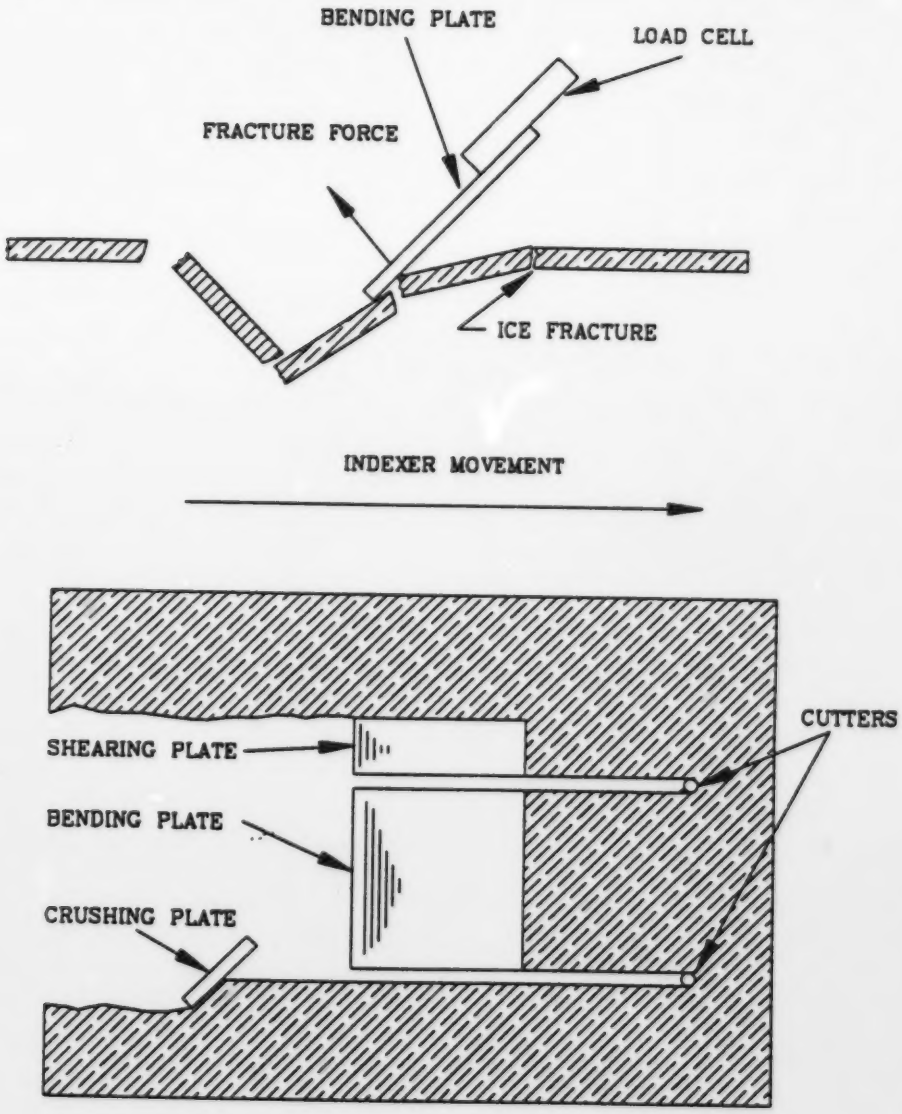
The first component is the ice cutter. In the earlier design these were rotating drills but have now been replaced with water jets. The objective of the cutter is to prepare two parallel cuts in the ice. The cuts have to be made quickly with the minimum disturbance to the ice.

Behind and between the cutters is an inclined plate that is angled down into the ice. As the cutters move ahead of the inclined plate, the ice comes into contact with the plate, is pushed down and fails in almost pure bending. It is important to note that the bending plate is slightly narrower than the distance between the two cutters, this ensures that the cantilever is broken symmetrically and that it is not influenced by the undisturbed ice sheet.

The crushing and shearing plates are located on opposite sides of the bending plate. The shearing plate is significantly narrower than the bending plate and is located adjacent to the bending plate and is also inclined with respect to the ice. One edge of the shearing plate is aligned with the cutter track while the outside edge extends into the unbroken ice sheet. As the plate advances into the ice a strip of ice is sheared off.

The crushing plate is located on the opposite side of the bending plate to the shearing plate. The crushing plate is mounted such that it angles into the uncut ice sheet. As the plate advances into the ice it crushes the edge of the cut track to a depth equal to its penetration.

FIGURE 2.1
CONCEPTUAL ARRANGEMENT OF THE INDEXER



INDEXER

The different ice thicknesses, strengths and speeds will influence the configuration requirement of the INDEXER and, as a result, the INDEXER must be sufficiently flexible to accommodate different plate widths, different plate angles and relative angular positions of the plates and cutters.

One primary objective of the INDEXER is to measure the mechanical properties of the ice as close to the test time as possible. This is necessary due to the decay of the ice properties over time. The INDEXER addresses this by permitting the experimenter to test the model ice strength either during the model test or directly after. The time delay between the test and the model ice characterization is therefore minimized and the interpolation or extrapolation to actual test time, necessary for conventional manual testing, is avoided.

3. MANUAL TEST EQUIPMENT

3.1 General

An accurate definition of material properties must employ a consistent measuring method and procedure. The strength of model ice has been shown to vary as a function of the measuring and calculation procedure (Timco 1981).

The mechanical properties of the majority of ice sheets used in model experiments conducted at the IMD have been measured using conventional, manual, testing methodology. This technique has involved the use of manually held spring gauges which are used to fail a cantilever beam cut in the ice. The results of the model experiments are then scaled to full scale values based on these measurements. The basis of this technique is that it simulates the full scale testing method.

Since most of the model ice sheets tested at IMD have used this measuring technique there is some understanding of how model scale performance may be related to full scale performance based on the numbers generated by the manual test methodology.

The INDEXER cuts, loads and breaks the ice using a different mechanical process and adopts a different set of algorithms to define strength, therefore it may be expected to generate different absolute strength numbers. Recognizing this difference it is necessary to develop a correlation between the conventional test procedures and the INDEXER. This will ensure continuity between the two methods and additional confidence in the results of the INDEXER. It may also be noted that since the ice strength must be continually monitored throughout the tempering cycle, the manual procedure for measuring ice flexural strength will likely never be totally replaced.

The following sections describe the manual test equipment developed for the correlation analysis.

3.2 Flexural Strength

The current system used by IMD to measure the flexural strength is to cut in-situ cantilever beams in the ice sheet, with a hand saw, and then load them to failure with a hand held spring load cell. There are two major problems with this method, firstly the ice forming the cantilever may be damaged by the action of sawing and secondly the force necessary to break the cantilever is dependant on the rate of load application and therefore, to some extent, on the technician conducting the test.

It was not considered possible within the scope of this project to develop a new cantilever cutting procedure. It may be noted however that IMD are currently developing an automatic beam cutting and loading frame (Pierce 1988). The second problem, loading rate, was addressed with a device, designed by IMD, that uses a controllable speed electric motor, drive shaft, yoke and strain gauge. The ice is cut, using a hand saw, in the conventional way and the device is positioned over the prepared beam. The motor drives a vertical shaft on which there is positioned a yoke attached to the load cell. Controlling the speed of the motor drives the yoke and load cell at a predefined speed. A plunger attached to the load cell is driven down onto the end of the beam and the time history of the failure is recorded. The device was designed by IMD and is illustrated in Figure 3.1. The output from the device was recorded with a KYOWA tape recorder and later redigitized for analysis.

3.3 Shear Strength

Various methods for measuring the shear strength of the model ice were available. The two main configurations considered were a guillotine and cylinder. The published tests by Timco (5) adopted a guillotine method. The test apparatus consisted of an aluminium box into which a premeasured rectangular piece of ice was inserted. The box was arranged with a hole so that a wooden plunger could be pushed down onto the ice thus shearing off the end. The ice was sheared parallel with the columnar crystal structure, from the top or bottom. The force required to shear the ice was recorded with a spring load cell. The equipment used by Dr. Timco for these experiments was available at IMD and had been used by Melville during a previous model test program. Our experience from those tests was that the equipment was difficult to use and not very consistent. It was also necessary to measure both the ice sample thickness and width prior to testing. The alternative configuration was to lay

FIGURE 3.1
MANUAL TEST EQUIPMENT FOR MEASURING THE
FLEXURAL STRENGTH OF THE MODEL ICE

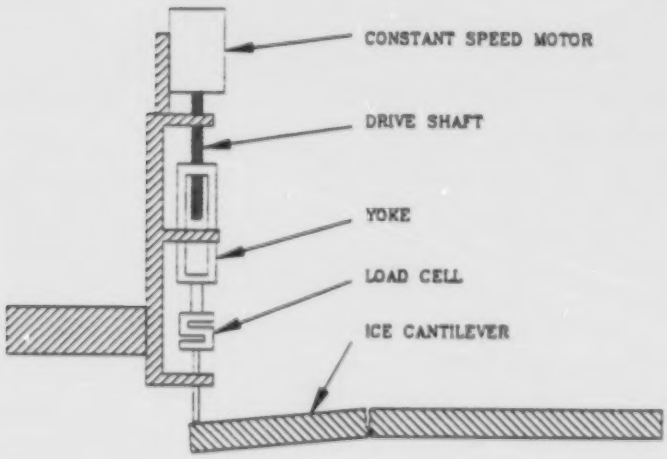
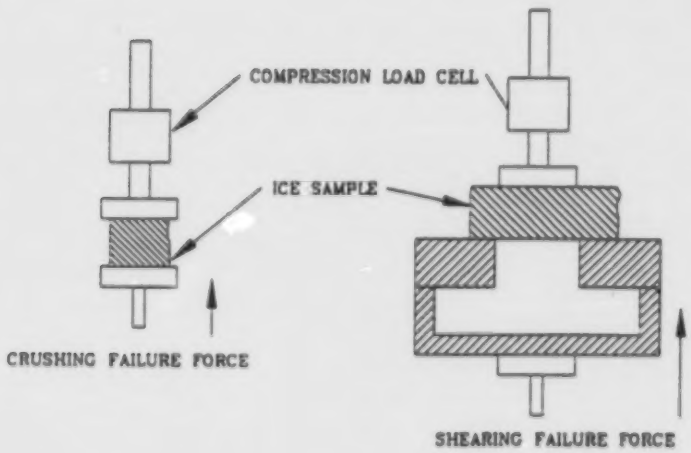


FIGURE 3.2
MANUAL TEST EQUIPMENT FOR MEASURING THE
CRUSHING AND SHEAR STRENGTH



an ice sample over a prepared hole and, using a plunger marginally smaller than the hole, punch a cylinder of ice through the hole. The shear area is therefore equal to the circumference of the hole, times the thickness of the ice. This provided a simpler and easier procedure and was adopted as the preferred method.

The plunger and base plate were integrated into a commercial test stand. The test configuration is illustrated in Figure 3.2.

3.4 Crushing Strength

The same apparatus used to measure the shear strength was also used for the crushing strength. The plunger was exchanged for a flat plate, and a solid base plate was used in place of the shear base plate. This setup is presented in Figure 3.2. A block of ice with length, width and height equal to the thickness of the ice sheet was prepared for use as the crushing sample. The ice was then crushed at constant speed to failure. The surface of both plates was covered with a rubber platen to prevent the block slipping and to ensure a consistent end constraint.

3.5 Test Stand

As noted above the crushing and shearing strength jigs were integrated into a commercial test stand. Although a custom designed stand was considered this was not found to be either practical or economical and a commercial stand was selected. The principle characteristics of the stand are given in Table 3.1. The selection of the stand was based primarily on the loading rate required and the range of loads that were anticipated. It was also necessary for the test stand, and load cell, to withstand the low temperatures and high humidity of the ice tank.

TABLE 3.1
TEST STAND PARTICULARS

Manufacturer	Chatillon; Model UTSM
Maximum Capacity	500 lb (223.2 kg)
Maximum specimen diameter	127 mm
Loading speed	24"/min (10.16 mm/sec)

4. DESIGN OF INDEXER

4.1 General

The main objective of Phase III of the INDEXER project was to improve the utility and performance of the INDEXER so that it can be used on a regular basis to measure the mechanical properties of model ice.

4.2 Ice Cutters

Previous INDEXER designs used two rotating drill bits to cut the ice for the three failure plates. The drills were originally powered by pneumatic drive motors to achieve the necessary high RPMs. These were replaced during Phase II by a single electric motor driving two belts which in turn drove the two drill bits. This arrangement required considerable maintenance to keep the drills functional, and the rotating mechanisms introduced considerable vibration. This excessive vibration could be seen as noise on the output signal from the load cells.

To avoid the problems of vibration and to take advantage of the recent development in water jet technology, it was decided to investigate the use of high pressure water jets to cut the ice for Phase III of the INDEXER. Water jets emit a high velocity solid stream of water that may be used for cutting materials as hard as stone. With respect to the ice it was envisaged that the jet would easily penetrate through the ice and leave a clean, undamaged edge. Since there would be no contact between the water jet assembly and the ice sheet there would be no in plane forces. It was believed that this would greatly reduce the vibration that was encountered with the rotating drills. It was also speculated that the water jets would be easier to maintain than the drills.

The design criteria that was developed for incorporating the water jets into the INDEXER are as follows:

a) The water jet assembly must be able to move in the x, y and z directions within a finite range.

b) The water jets must be able to cut cantilever beams ranging from 40 mm to 200 mm in width and 100 mm to 500 mm in front of the bending plate.

c) The water jets must be able to penetrate ice up to a thickness of 150 mm.

d) The water jets must be compatible with the high pressure pump available at IMD.

In order to investigate the water jet option, the IMD, in association with Melville, conducted a series of tests with several different ice thicknesses and ice strengths in the model ice at IMD. The model ice currently used by IMD is a dopant of ethylene glycol, aliphatic detergent, and sugar (EG/AD/S). The tests were conducted in the Spring of 1989 to define the relationship between the water jet parameters and their ice cutting capability. The results from these tests were used to select the appropriate water jet system for the INDEXER.

Three different nozzle diameters were tested to determine the optimum nozzle, water pressure, flow rate, kerf width and stand off distance for cutting model ice. Figures 4.1 and 4.2 present a diagrammatic of the test setup and show the parameters which were measured during the tests. The "stand off" distance is defined as the distance between the ice surface and the nozzle and the "kerf width" is defined as the width of the water jet cut. Each nozzle was tested on 40 mm and 80 mm ice sheets at strengths of 20, 40 and 60 kPa. Unfortunately it was not possible to test the maximum ice thickness criteria defined for the INDEXER of 150 mm, however since the large majority of INDEXER testing will be below 80 mm it was elected to focus on the 80 mm testing. For each test the carriage travelled the full length of the ice tank at varying speeds with one nozzle working per run. The penetration, stand-off distance, kerf width, pump exit pressure and nozzle inlet pressure were recorded. These parameters are shown in Figure 4.2.

The results of the 80 mm tests are presented as Penetration versus Carriage speed in Figure 4.3 for the 60 kPa ice sheet, Figure 4.4 for the 40 kPa ice sheet and Figure 4.5 for the 20 kPa ice sheet. The figures show the penetration from zero, the ice surface, down to 80 mm for each of the carriage speeds, 0.5, 1.0, 2.0, and 3.0 m/sec. Within each carriage speed the figures present the measured average penetration for seven different combinations of pressure and nozzle diameter. The nozzle diameters tested were 1.0, 2.0 and 3.0 mm and are identified as N1, N2 and N3

FIGURE 4.1
SCHEMATIC OF
WATER JET TEST ARRANGEMENT

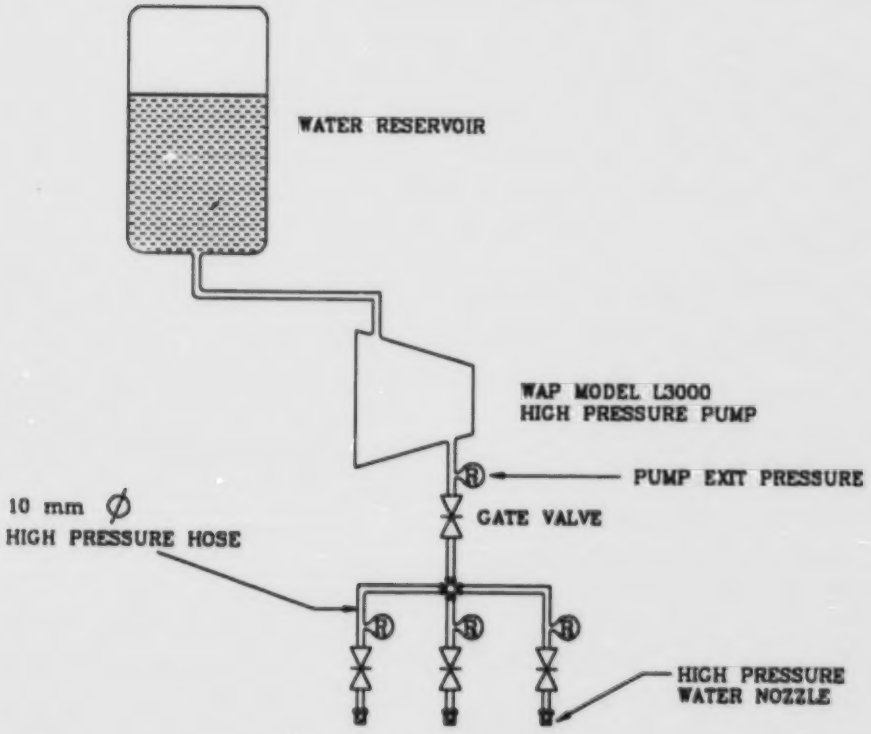


FIGURE 4.2
WATER JET TEST PARAMETERS

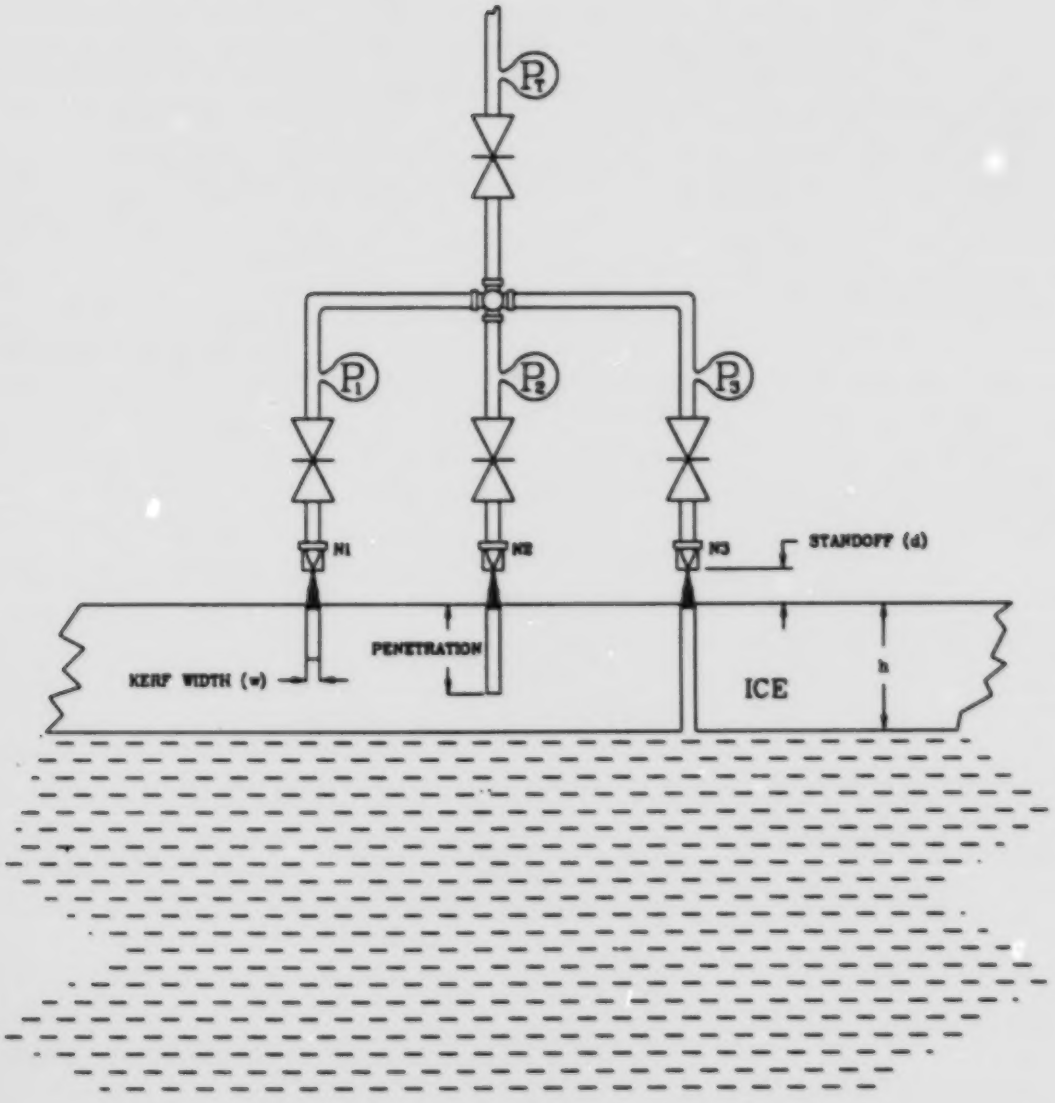


FIGURE 4.3
PENETRATION vs CARRIAGE SPEED
FOR THE WATER JET CUTTERS
80 mm ICE @ 60kPa

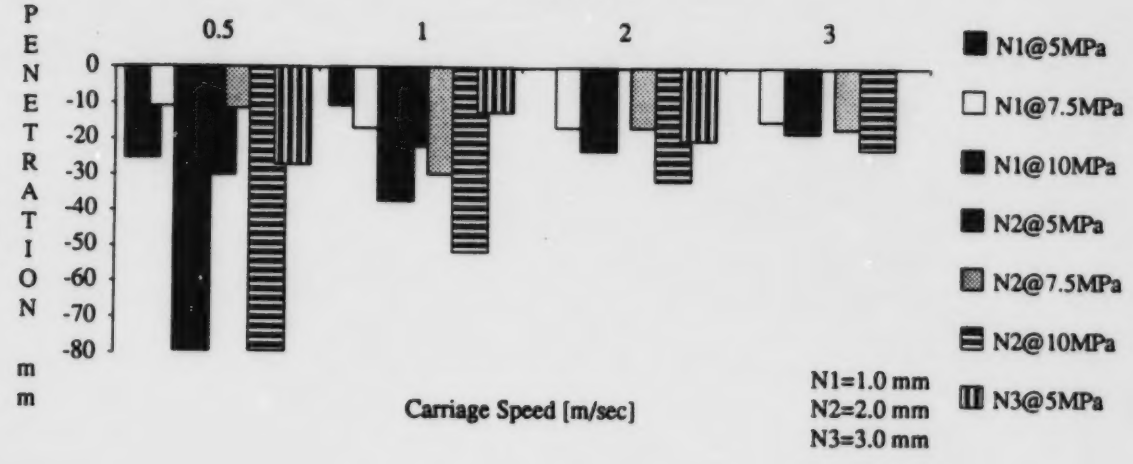


FIGURE 4.4
PENETRATION vs CARRIAGE SPEED
FOR THE WATER JET CUTTERS
80 mm ICE @ 40 kPa

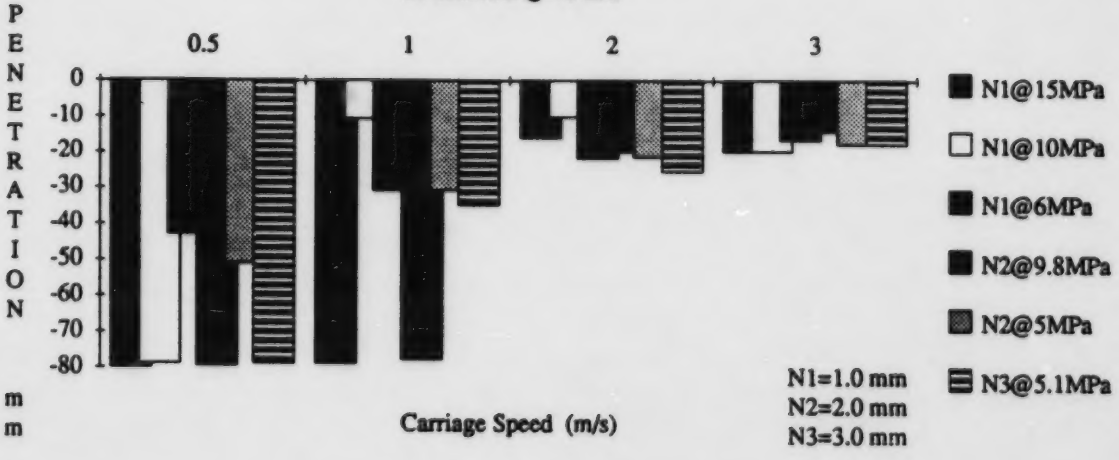
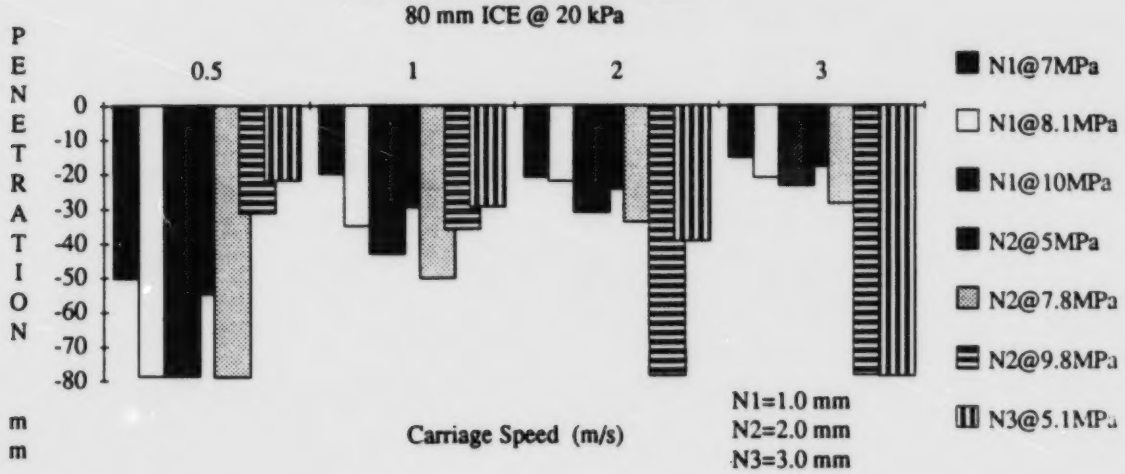


FIGURE 4.5
PENETRATION vs CARRIAGE SPEED
FOR THE WATER JET CUTTERS
80 mm ICE @ 20 kPa



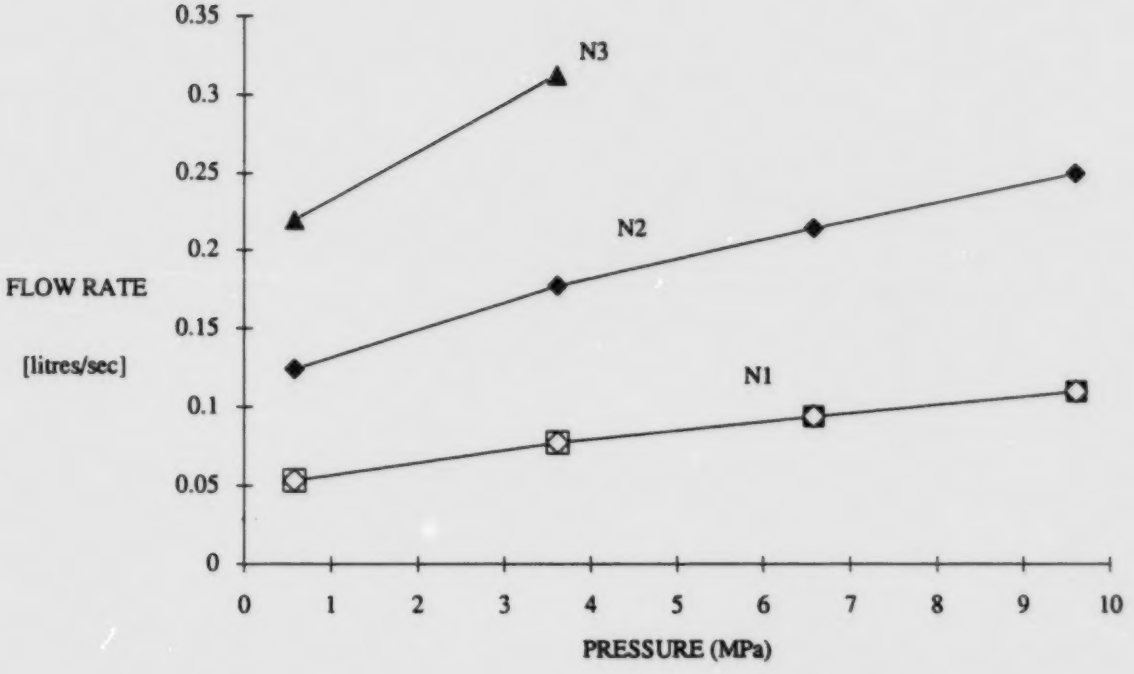
respectively. For example, it may be easily seen from the figures that at 0.5 m/sec in 60 kPa ice, two nozzle/pressure combinations penetrated the ice sheet, the 1.0 mm nozzle with 10 MPa pressure and the 2.0 mm nozzle with 10 MPa pressure.

It is envisaged that the INDEXER will operate at a carriage speed of less than 0.5 m/s. Figures 4.3 to 4.5 show that at a speed of 0.5 m/s and an inlet pressure of 10 MPa, the 1 mm and 2 mm nozzles penetrate to a depth greater than 80 mm at all ice strengths. It was therefore concluded that either the 1 mm or 2 mm nozzle would be sufficient for the needs of the ice cutter, however the 1 mm nozzle was cho^Xxn because of its lower flow rate which would have a smaller demand on the limited water reservoir. Figure 4.6 presents the relationship between flow rate and pump pressure for the three nozzles.

Although the scope of water jet testing for the INDEXER is limited to the full penetration of the ice there are trends with the pressure and nozzle combinations. Larger nozzles, for the same pressure, imply higher flow rates and therefore more water mass and a higher exchange of kinetic energy into the ice. It may be noted that;

a) As the pressure increases for a given nozzle the penetration generally increases. It may be noted that this is not always the case, for example the 1.0 mm nozzle in 60 kPa ice at 0.5 m/sec has a lower penetration at 7.5 MPa than at 5 MPa, although it must be recognized that this could also be due to a hard spot in the ice.

FIGURE 4.6
WATER JET FLOW RATE vs PUMP PRESSURE



b) It is unknown why the 3.0 and 2.0 mm nozzles in 20 kPa ice at 9.8 and 5.1 MPa respectively should cut through the ice more efficiently at higher speeds.

c) The higher flow rates, larger nozzles, tended to result in more efficient cutting. Unfortunately they also required higher volumes of water and therefore would have limited duration given the storage tank limitations.

The kerf width was also found to vary as a function of nozzle size and velocity. Figures 4.7, 4.8 and 4.9 illustrate the Kerf Width vs Carriage Speed for the three nozzles at 5.0 MPa. With respect to the INDEXER application it is important that the kerf width provides sufficient clearance between the bending plate, the shearing plate and the crushing plate to avoid interference. It may be observed from the figures that in the testing range envisioned, from 20 to 60 kPa, the kerf width is about 5 mm which is considered to be more than adequate for the INDEXER.

FIGURE 4.7
KERF WIDTH vs CARRIAGE VELOCITY
OVER A RANGE OF ICE STRENGTH ; 1.0 mm NOZZLE
NOZZLE PRESSURE = 5MPa

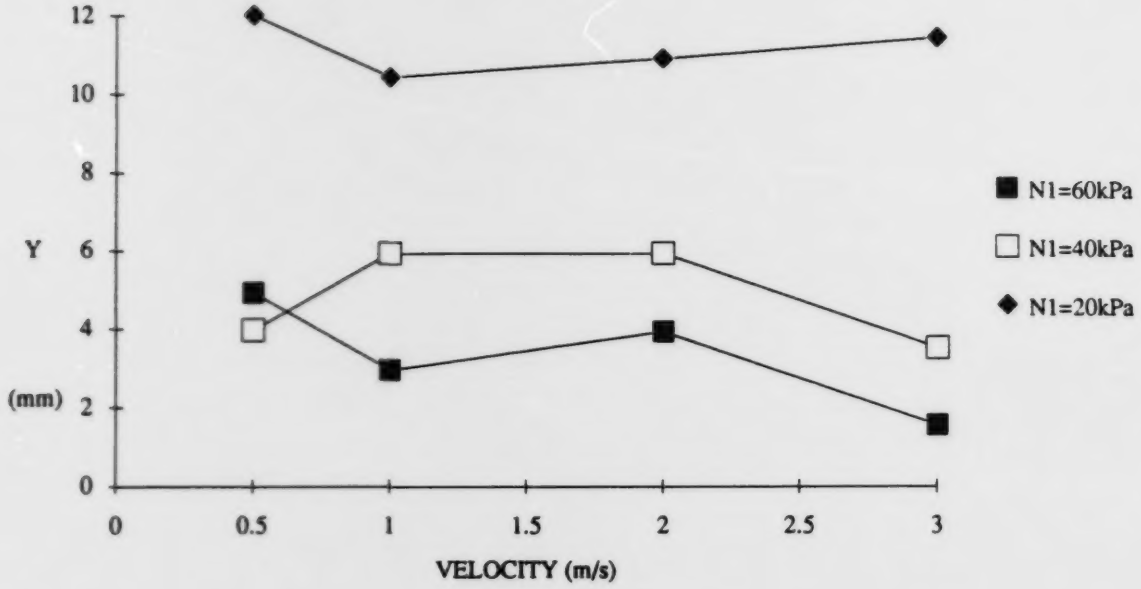


FIGURE 4.8
KERF WIDTH vs CARRIAGE VELOCITY
OVER A RANGE OF ICE STRENGTH ; 2.0 mm NOZZLE
NOZZLE PRESSURE = 5MPa

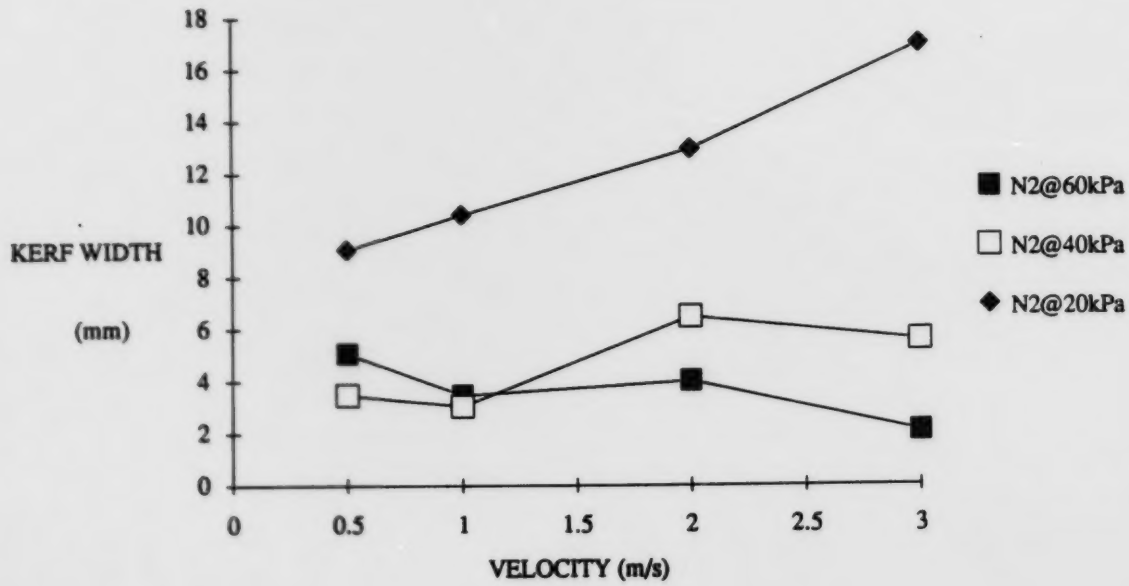
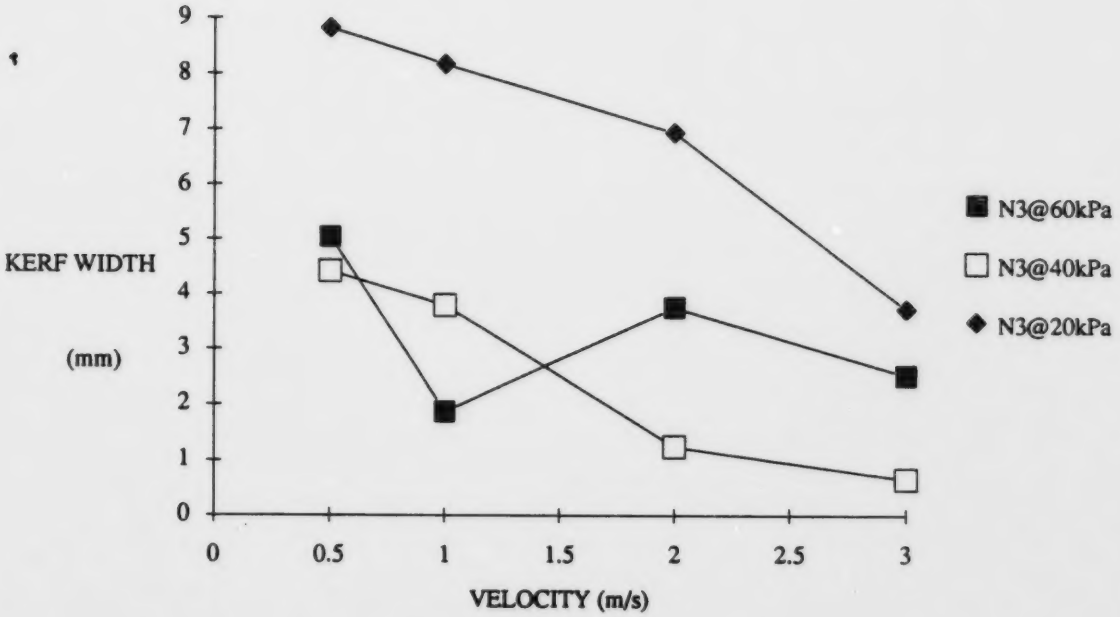


FIGURE 4.9
KERF WIDTH vs CARRIAGE VELOCITY
OVER A RANGE OF ICE STRENGTH ; 3.0 mm NOZZLE
NOZZLE PRESSURE = 5MPa



Subsequent tests highlighted the added benefit to the nozzles by adding a flow adapter. This was a small insert placed on the pressure side of the nozzle and introduced a flow rotation in the water stream. The influencer of this on the water jet was to produce a more powerful and "focused" water jet that was capable of cutting thicker ice. Based on the observations made during the tests and the introduction of the flow adapter it was elected to use the 1 mm jet nozzle, with the flow adapter, at 10 MPa of water pressure.

4.3 Plate Configuration

The testing and analysis of the INDEXER during previous phases of the INDEXER development highlighted a number of design changes that would improve the utility and functionality of the INDEXER. These were:

a) There was significant mechanical friction in the hinges of the crushing, shearing and flexural plates that was influencing the recorded ice forces.

b) Manual tests are conducted using a cantilever beam with a length, width and thickness ratio of 5:2:1. This same ratio was used for the bending plate during the early^XxNDEXER tests in an attempt to duplicate the manual tests. However, because of the high length to width ratio of these beams they were not sufficiently strong to develop a high breaking force that could be distinguished from the other forces on the plate.

c) The shear plate was experiencing a significant bending failure component and was also believed to be subject to torsional loads which might affect the output of the load cells.

Considering these and other potential modifications identified during the previous testing, the INDEXER was redesigned based on the following general principles;

a) The bending, shearing and crushing plates should be supported by the load cell with no other mechanical connection.

b) The plates and load cell configuration should be designed to ensure that the forces being recorded were not subject to twisting loads.

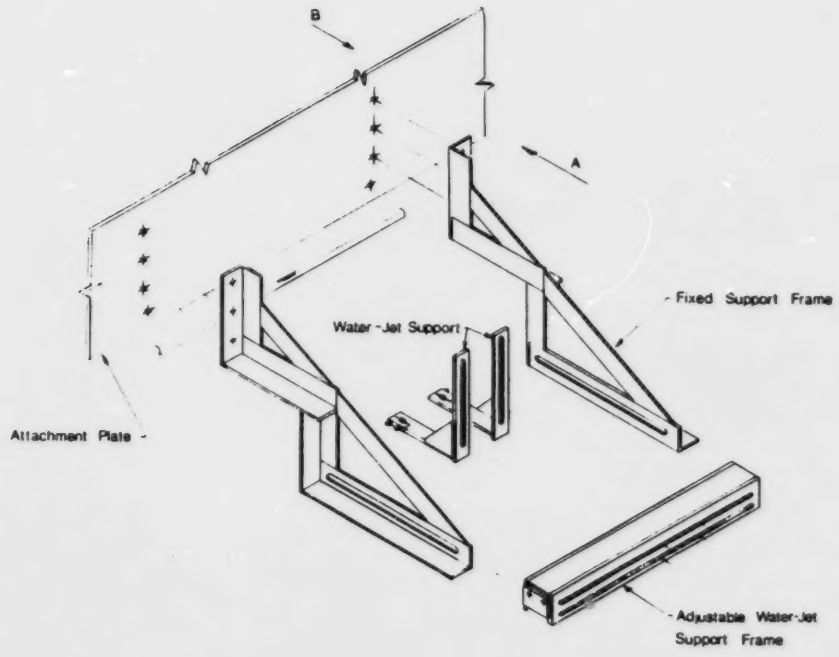
c) A range of plate sizes should be made to permit flexibility in the selection of anticipated forces for different ice thickness tests.

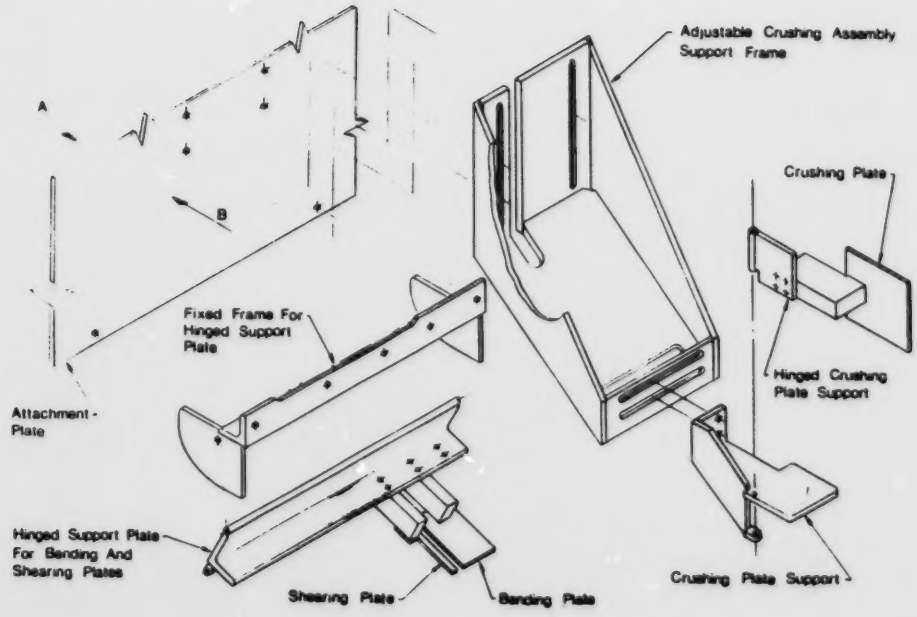
Based on these design criteria the INDEXER was modified as shown in Figure 4.10. During the design development a number of compromises were made, these are discussed in the following paragraphs.

The load developed on the bending plate was uniform across its lower edge and, as a result, could be easily supported with simple cantilever load cells. However, both the shearing and crushing plates were not subject to symmetrical loading. As a result it was elected to use "Platform" load cells which offer a number of advantages

FIGURE 4.10

EXPLODED VIEW OF THE MODIFIED INDEXER





over the cantilever cells. The major advantage was that, because the cells only measure in plane forces, they are not influenced by the point of application of the load on the plate. This reduced the potential for error associated with out of plane forces, or twisting, or establishing the point of load application which was necessary with the cantilever load cells.

To confirm the performance of these platform load cells they were tested in the configuration shown in Figure 4.11. A wide plate, with a matrix of holes spaced 20 mm apart, was secured to the load cell. By using each hole to secure a 20 kg weight it was possible to establish the influence of bending moments on the cell. The results of the experiment are shown in Table 4.1 for a typical test. It can be seen from the figure that the output from the load cell, shown in millivolts, is uniform over the whole plate. This result confirmed that the load cell was performing correctly and only recording the vertical component of the force.

TABLE 4.1

RESULTS FROM CALIBRATION OF 75 kg LOAD CELL

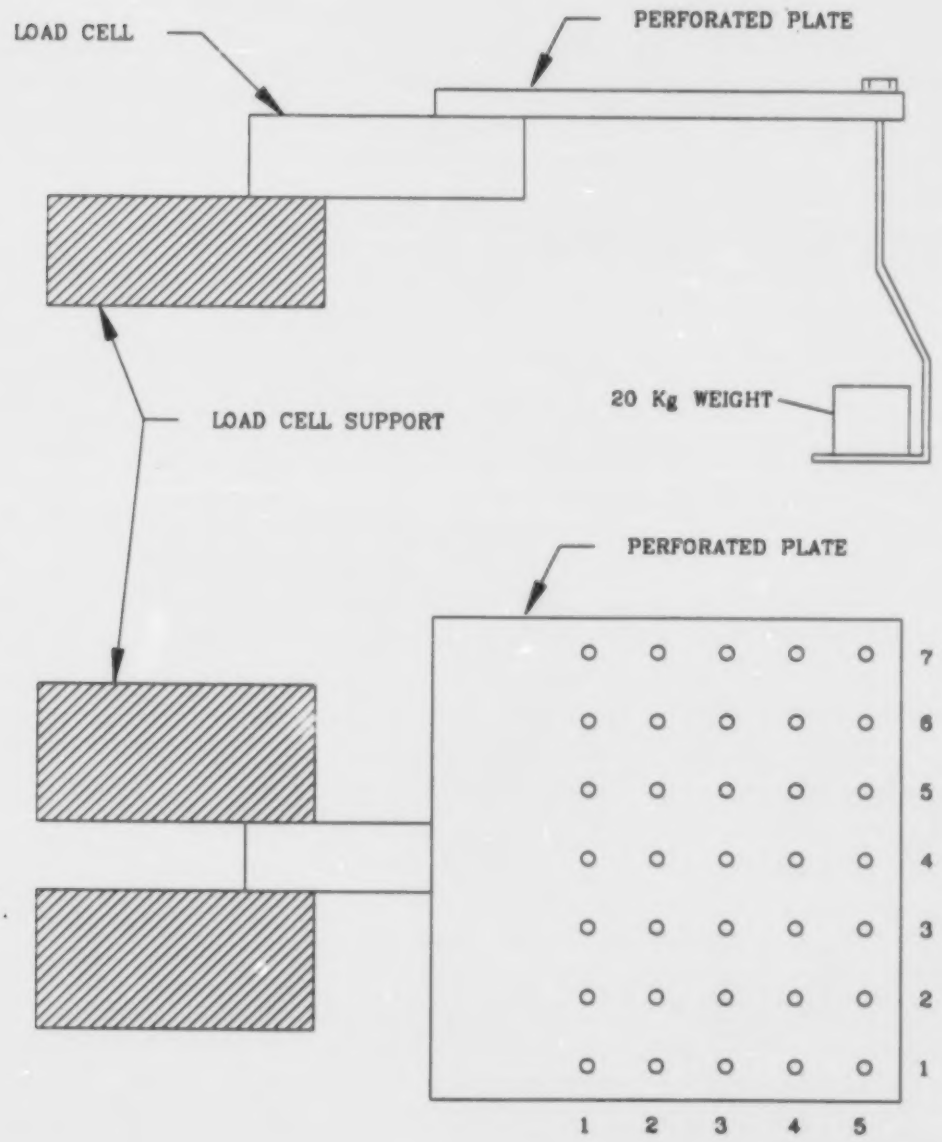
POSITION OF LOAD , OUTPUT IN MILLIVOLTS

	1	2	3	4	5	6	7
1	6.1645		6.1652		6.1640		6.1655
2		6.1642		6.1648		6.1656	
3	6.1640		6.1648	6.1648	6.1652		6.1655
4		6.1640		6.1648		6.1652	
5	6.1633		6.1642		6.1642		6.1650

Note: Numbers Relate to Position of Load attachment to the perforated plate, ref. Figure 4.11

Excitation Voltage = 10.0000 Volts D.C.
No Load Voltage = +0.3347 mVolts D.C.

FIGURE 4.11
TEST ARRANGEMENT FOR THE
PLATFORM LOAD CELLS



NOTE; Numbers on perforated plate refer to table 4.1

The range of beam widths and ice thicknesses presented a series of difficult design problems for the INDEXER configuration. An important consideration was to achieve a minimum flexural cantilever length whilst maintaining a small angle of attack for the plate. To achieve this it was necessary to position the bending plate as close as possible to the water jets. This was finally accomplished by using a cantilevered water jet support and the load cells connected to the top of the bending and shearing plates.

The range of ice thicknesses required that the INDEXER be lowered close to the ice surface to achieve sufficient ice penetration for the plates. However, it was also necessary to lift the INDEXER 400 mm clear of the ice surface. This resulted in a large vertical range of motion which was not possible with the INDEXER support frame alone and it was necessary to design an additional adjustment on the lowest part of the INDEXER, the crushing plate support.

The detailed design drawings of the final INDEXER design are available through TDC.

4.4 INDEXER Platform Support

During all the previous tests of the INDEXER it had been supported on the ice tank carriage using a temporary arrangement of clamps. The result was that it was difficult to maintain, adjust the failure plates and observe the failure action during operation. Furthermore it was practically impossible to move the INDEXER laterally across the ice sheet. To correct these shortfalls it was elected to design and construct a support frame for the INDEXER that would permit the INDEXER to be quickly raised and lowered and moved laterally across the full width of the ice tank.

The previous tests highlighted a number of potential major design improvements:

a) The INDEXER should be supported on a platform that would provide easy access for adjustments and detailed observations whilst in operation.

b) The platform should be capable of deploying the INDEXER in any lateral position across the ice tank for testing.

c) The platform should be capable of deploying the INDEXER facing in either direction to permit tests to be conducted up or down the ice tank.

The conceptual design of the INDEXER support frame was completed by Melville and the final design and fabrication undertaken by NORDCO Ltd. of St. John's, Newfoundland.

A series of design compromises were made during the design of the platform and these are described in the following paragraphs.

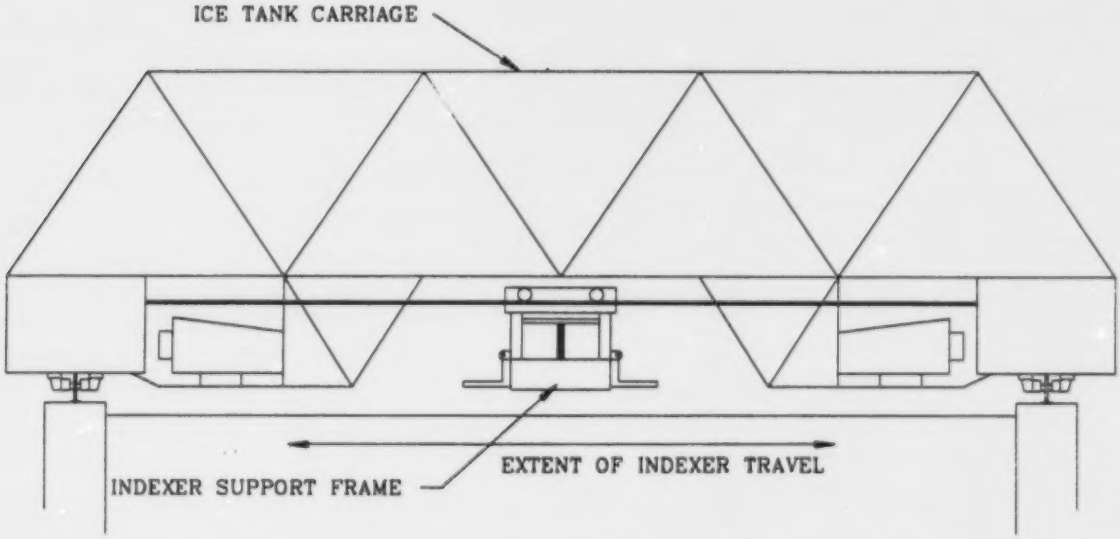
Due to the configuration of the ice tank carriage and the underwater camera carriage driving post it was necessary to position the platform at the front, or west end, of the ice tank carriage. Unfortunately, this area was also used for the carriage drive motors and, as a result, it was not possible to deploy the INDEXER across the full width of the tank. However, model tests are largely confined within the middle 50 to 60% of the tank's width and this area was well covered by the lateral range of the proposed INDEXER platform.

The platform was designed so that the INDEXER could be tested both moving along the tank east to west, the normal direction of a model test, and west to east. This was desirable so that the INDEXER could be used simultaneously with a model test, moving east to west, or on the carriage's return down the tank, west to east, immediately following a model test.

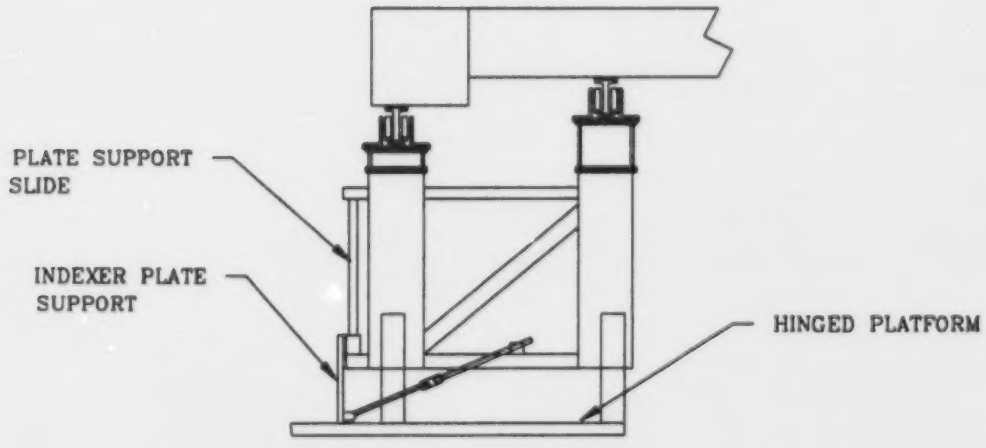
Since the platform would be suspended below the ice tank carriage it was necessary to develop a procedure to remove and install the platform without the use of an overhead crane. The procedure adopted was to ensure that there was sufficient space below the platform to float in a set of the ice tank floats. The ice tank floats are interlocking plastic cubes that are used by the technicians to gain access onto the ice tank. Using this procedure the INDEXER platform could be lowered onto the ice tank floats and moved to the tank side for removal.

Figure 4.12 illustrates a schematic of the tank carriage and INDEXER platform support, the detailed design of the INDEXER platform is available from TDC.

FIGURE 4.12
SECTION OF ICE TANK CARRIAGE AND
INDEXER SUPPORT FRAME



SECTION THROUGH ICE TANK CARRIAGE



PROFILE OF INDEXER SUPPORT FRAME

5.0 INDEXER SOFTWARE APPLICATION

5.1 General

The presentation and analysis of the INDEXER output is unique and required custom designed software. The application designed and developed for the INDEXER is illustrated in Figure 5.1 and described in detail in Appendix 1. The application may be divided into three main sections;

5.2 Data Input

The data input section permits the user to read and input any ASCII (American Symbolic Code for Information Interchange) file that contains the multiplexed time sequence data from the load cells. The data is then converted into Binary format which takes substantially less space in the computer memory. In addition to the time series data the application also permits the user to input important INDEXER variables, such as plate widths and angles, together with the manual records of the ice strength. Each data entry is associated with a HELP feature and permissable ranges of the input variable. This ensures that the user does not inadvertently input a grossly wrong number which may occur, for example, by missing a decimal point.

The different data types are organised into different files. The raw ASCII data is in *.DAT files, the converted raw data, in Binary format, is stored in *.BIN files, the manually recorded data is in *.MNL files, the analyzed data is in *.ANL files and the results are stored in *.TBL files. If the analyzed or manual files exist for any force time history file then they will be loaded automatically with the force time history file. Each file is discussed in more detail in Appendix 1.

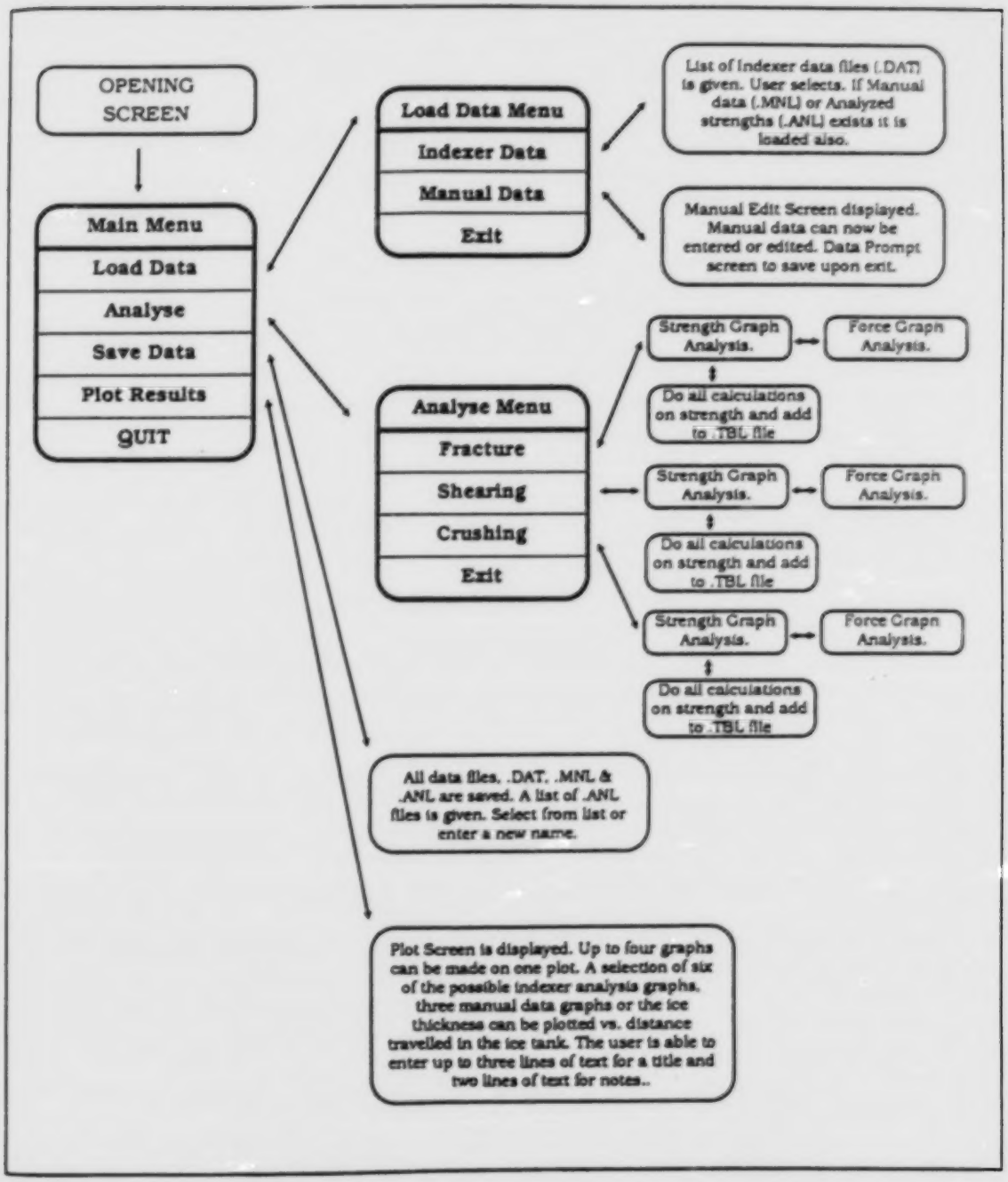
5.3 Data Analysis

There are four channels of raw data time series input from the INDEXER; Bending plate force, Shearing plate force, Crushing plate force and INDEXER speed.

FIGURE 5.1

LOGIC FLOW DIAGRAM FOR THE INDEXER

ANALYSIS APPLICATION


OPENING SCREEN
Main Menu
Load Data
Analyse
Save Data
Plot Results
QUIT
Load Data Menu
Indexer Data
Manual Data
Exit
List of Indexer data files (.DAT) is given. User selects. If Manual data (.MNL) or Analyzed strengths (.ANL) exists it is loaded also.
Manual Edit Screen displayed. Manual data can now be entered or edited. Data Prompt screen to save upon exit.
Analyse Menu
Fracture
Shearing
Crushing
Exit
Strength Graph Analysis.
Force Graph Analysis.
Do all calculations on strength and add to .TBL file
Strength Graph Analysis.
Force Graph Analysis.
Do all calculations on strength and add to .TBL file
Strength Graph Analysis.
Force Graph Analysis.
Do all calculations on strength and add to .TBL file
All data files, .DAT, .MNL & .ANL are saved. A list of .ANL files is given. Select from list or enter a new name.
Plot Screen is displayed. Up to four graphs can be made on one plot. A selection of six of the possible indexer analysis graphs, three manual data graphs or the ice thickness can be plotted vs. distance travelled in the ice tank. The user is able to enter up to three lines of text for a title and two lines of text for notes..

The data analysis transforms the force time series into strength position data for each channel. The tank position is calculated from an integration of the speed data. The mathematical calculation of the force series is described in Appendix 1. The following paragraphs summarize the analysis.

The force time history of the bending plate is characterized by a low noise level interspersed with peak forces that represent the fracture of each cantilever. The analysis program automatically identifies the magnitude and location of each peak. Based on this information the stress to fail the ice is calculated using simple cantilever equations where the peak force is the failure load, the distance between adjacent peaks is the length of the cantilever, the distance between the water jets is the cantilever width and the ice thickness is the cantilever depth (Baker 1987).

The shear failure is calculated in a similar way using the peak force generated by the plate. However, the length of the failure, or shear area, is calculated by evaluating the distance from the peak to the point at which the force forming the peak starts to rise. The rational for selecting this interval is explained in more detail in section 6.

The crushing failure is calculated from the peak forces recorded from the load cell and the width of the crushing plate interacting with the ice.

Within the analysis section of the software are a number of additional features that enhance the flexibility of the peak selection criteria and the presentation of the INDEXER output. These are discussed in Appendix 1 but may be summarized as;

a) The user may select to view either the force or calculated strength series of data.

b) The user may elect to view the results from the manually recorded data in conjunction with the INDEXER data.

c) The user may easily establish the INDEXER / manual data correlation by adjusting a correlation factor built into the application.

d) The user may select to filter the strength data using an adjustable moving average filter.

e) The user may enlarge any section of the force/position or strength/position data using a "Zoom" function.

f) Within any selected window of data the user may conduct a discrete analysis. This will result in the mean, maximum, minimum, standard deviation within the sample bounds. The results of this analysis may be stored in a file for later analysis or hard copy printing.

g) Once the user has conducted an analysis on the data it is saved in that form. This permits data that has been analyzed to be "re-visited" and the original analysis will still be intact.

5.4 Data Presentation

The computer application incorporates an extensive plotting capability which permits the user to select from a range of different plotting functions. In summary the user may:

a) Select any set of variables, for example ice thickness, manual ice flexural strength, INDEXER flexural strength, etc, etc, and plot up to four at any one time.

b) The user has the option to include titles and notes on each plot.

c) The user may plot filtered or unfiltered data.

6. INDEXER TESTS

6.1 General

The INDEXER was tested during August and September 1989 at the Institute for Marine Dynamics in St. John's Newfoundland. The tests were conducted in a total of four ice sheets that covered a range of ice thickness from 30 to 65 mm. The tests were conducted by repeatedly running the INDEXER down the ice tank at different speeds and at different times during the ice tempering process which permitted the INDEXER to be tested in a range of different ice thicknesses and strengths.

Table 6.1 summarises the tests conducted on the INDEXER. It may be noted that, due to experimental problems, the first two ice sheets were not used in the following analysis.

The following sections describe the results from the INDEXER tests using example outputs. The complete set of analyzed runs is available from TDC, together with the application, on a computer floppy disc.

TABLE 6.1

INDEXER TEST PROGRAM

ICE SHEET #	DATE	ICE THICKNESS [mm]	INITIAL STRENGTH [kPa]	TEST SPEED [m/sec]
INDEX2	30/8/89	30	60	-
INDEX3	01/9/89	30	60	0.08, 0.1, 0.12, 0.16
INDEX4	06^Xx/89	50	60	0.08, 0.1, 0.12, 0.16
INDEX5	08/9/89	65	60	0.08, 0.1, 0.12, 0.16, 0.2, 0.3

6.2 Test Results

6.2.1 General

The force data from the tests were analyzed using the INDEXER software as described in section 5.3. The analysis was conducted in a number of steps. First the INDEXER force outputs, from each load cell, were manually reviewed to identify areas of inconsistency and assure that the automatic data analysis, conducted by the computer program, was functioning correctly. The forces are presented as force-position data along the ice tank. Part of this review of the force-position history involves the selection of the criteria by which the application selects the peak forces.

Once the forces have been reviewed the user may proceed to the analyzed strength data. The strengths are calculated using the algorithms and criteria described in detail in Appendix 1. In addition to the INDEXER strength data, the application also presents the user with the manual strength data. This permits a direct comparison between the INDEXER output and the manual strength results. As discussed elsewhere in this report the ice strength values from the INDEXER were not anticipated to be the same as the manual ice strength values. This is due to different measuring techniques and different failure strain rates. To permit a direct comparison a "Correlation Factor" was introduced into the INDEXER program. The preliminary correlation factor was a variable that could be added to each of the INDEXER strength values to equate them to the manual strength values. As discussed below, this preliminary correlation factor was later augmented by a second variable which was used in a multiplication with each of the INDEXER strength values. These two factors are referred to as the "sum" and "product" correlation factors throughout the rest of the report. The analysis in the remainder of this section adopts the "sum" correlation factor.

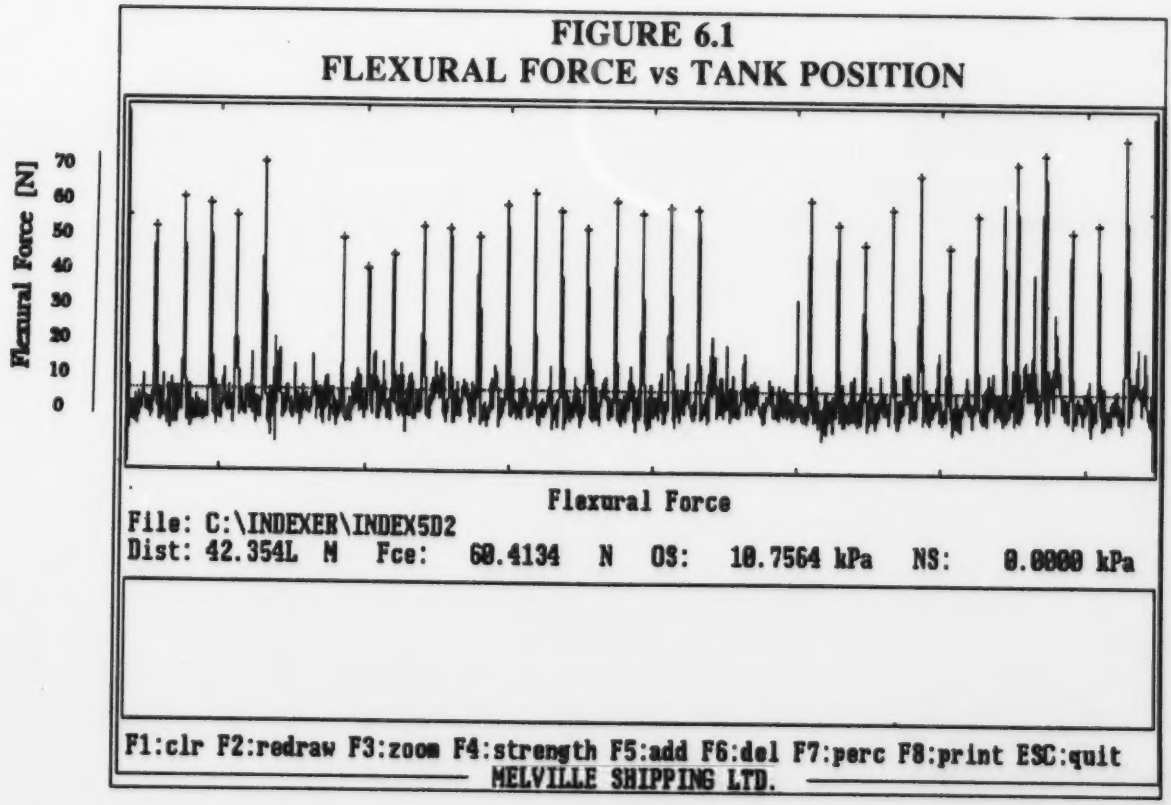
Based on these correlation variables the user may select the appropriate factors that will adjust the INDEXER output to the same values as the manual strength analysis. A correlation factor was determined for each carriage velocity, ice thickness and nominal ice strength. It should be noted that separate correlation factors were determined for the flexural, shearing and crushing strength. The analysis is described in more detail in the following sections. It may be noted that the dependence of the INDEXER output on carriage velocity was not unexpected considering the documented influence of strain rate on ice failure (Timco 1981). However, since the INDEXER's primary function is to measure the mechanical properties of the ice, once a suitable test speed has been established, it is envisaged that the carriage speed will be held

constant for all subsequent tests, regardless of the test or model speed, to minimize the number of variables introduced into the correlation.

6.2.2 Flexural Strength

The force time history for the bending plate was typified by large peak forces approximately 200 mm apart. An example of the output is illustrated in figure 6.1. Figure 6.1 is the plotted output from the INDEXER application and illustrates the forces being generated on the bending plate over a one meter length of tank. The axis values have been superimposed on the figure to add clarity and permit some understanding of the peak magnitudes whilst reading this report. They do not appear on the computer screen since the value of any point may be determined by moving one of the cursors to its position. The figure illustrates a typical time history in which the crosses identify the force peaks selected by the computer program and used as the failure force in the strength algorithm. It may be noted that this figure was created using the "Zoom" and "Plot" capability of the application.

FIGURE 6.1
FLEXURAL FORCE vs TANK POSITION



Additional information on Figure 6.1, directly below the plot, is the file name, C:\INDEXER\INDEX5D2. Below the file name is the position of the left cursor, 42.354 m (the "L" following the position value designates the left cursor), the force value at the left cursor, 60.4134 N, and two strength values. The two strength values are used to assist in the selection of peak forces and are calculated with respect to the selected cursor. The first, "OS: 10.7564 kPa", designates the calculated strength based on the previous peak force and distance, the second, "NS: 0.0000 kPa", presents the user with the calculated value of the flexural strength if the current position of the cursor was used as a force peak.

The function key list at the bottom of the screen includes the F1; Clear display and redraw, F2; Redraw existing display, F3; Zoom, F4; Move to strength analysis, F5; Add peak force, F6; Delete peak force, F7; Selection of minimum peak line, F8; Print screen and ESC; to escape from the screen.

It may be observed that between the peaks there is some noise due to the vibration of the load cell believed to be caused by hydrodynamic forces and vibration of the ice tank carriage and INDEXER support frame. However, the noise is not significant with respect to the peaks. The figure also shows a "window" of no peaks occurring at the beginning of the trace and just to the right of the centre. These areas are the result of the INDEXER passing through a manual test site in the ice in which the ice had been removed. It can be seen that the peaks in this area have not been selected and is an example of why the user must be capable of editing the automatic selection of force peaks.

The associated ice strength is calculated from the force peaks. An example of the INDEXER output, taken from the analysis screen of the computer application, is shown in Figure 6.2. Figure 6.2 illustrates the calculated flexural strength over approximately the same area of ice as the force time series in figure 6.1. The data has been filtered using a moving average filter and the selected "Window" has been analyzed. It may be noted that the analysis of the selected area includes the calculated crushing and shearing strengths for the same window.

FIGURE 6.2
FLEXURAL STRENGTH vs TANK POSITION

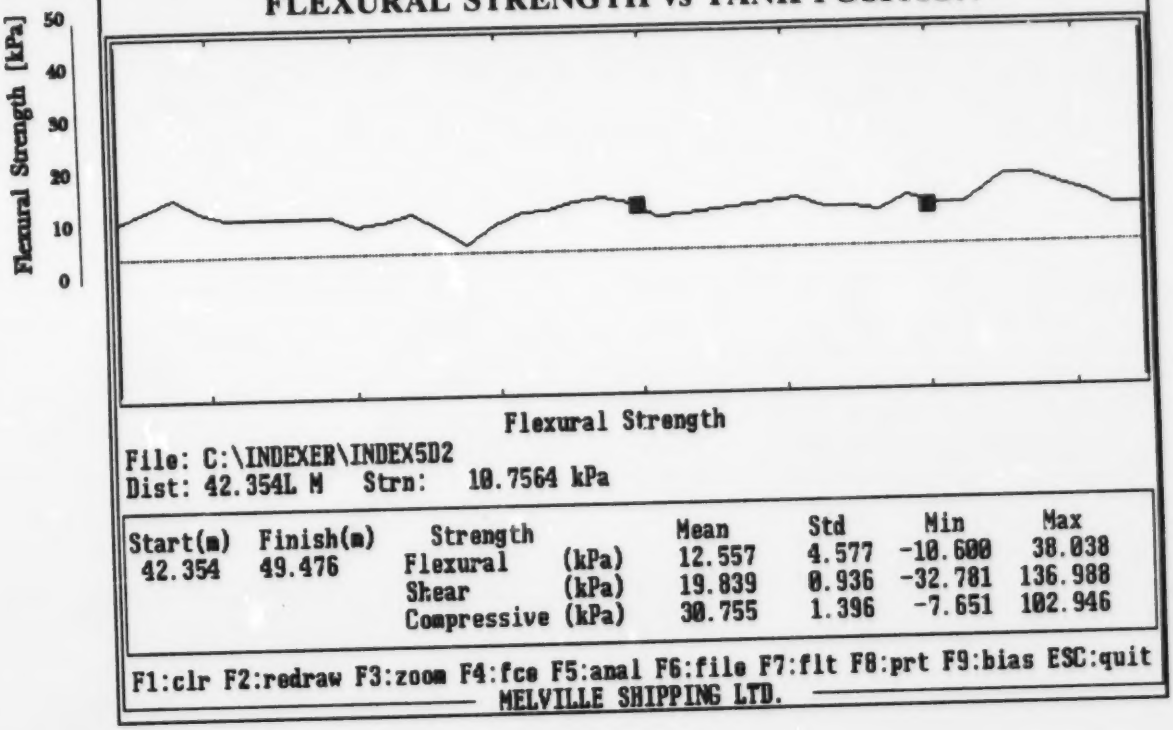


Figure 6.2 also shows manual data points that are associated with this sample interval. The manual data points are shown as a square. It should be noted that the INDEXER data shown in this figure has been adjusted, using the correlation factor, to be representative of the manual record.

As discussed above, the strengths calculated from the INDEXER output have different absolute values than the manual strengths. This is due to the different failure mechanisms utilised by the INDEXER as compared to the manual strength data. The data is modified with the correlation factor applied to the INDEXER data.

The screen display shown in Figure 6.2 is similar to the force screen shown in Figure 6.1. The function keys along the bottom of the screen are also similar with the exception that the F4 key moves the user back to the force output, the F5 key executes an analysis of the selected window, the F6 key stores the analyzed data, the F7 key

adjusts the moving average filter, the F8 key prints the screen and the F9 key adjusts the bias.

Based on an analysis of the data, a series of "sum" correlation factors were developed for each ice thickness, strength and carriage velocity. Figure 6.3 illustrates the relationship between the INDEXER correlation factor and the manual strength records. There is no apparent trend between the correlation factor and manual flexural strength and although there is a trend for higher speeds to have higher correlation factors, the trend will require additional testing to establish a broader data base before any conclusive relationships can be developed.

The carriage velocity had the greatest influence on the flexural force and this relationship is shown in Figure 6.4, which presents the correlation factor versus INDEXER speed. Each data point represents a different strength. Although only a limited number of tests were conducted there does appear to be a strong influence of speed on the correlation factor. This relationship can be further developed with additional tests with the objective of establishing a speed range that has the lowest dependency.

Operationally it is advantageous to have a high carriage velocity to minimize the time necessary to conduct an INDEXER run. At 0.08 m/s one run down the length of the tank would take nearly 13 minutes, while at 0.3 m/s it would take only 3.5 minutes. The time factor also impacts significantly on the volume of water necessary to operate the water jets. At the slower speeds, the water reservoir had to be refilled after each run, at the higher speeds three runs could be completed before refilling. However the higher speeds did cause larger forces on the bending plate, approaching the maximum capability of the load cells. It also caused considerable water to be washed up on the ice surface, which is believed to have an adverse effect on the tests.

FIGURE 6.3
FLEXURAL STRENGTH CORRELATION FACTOR
vs MANUAL FLEXURAL STRENGTH

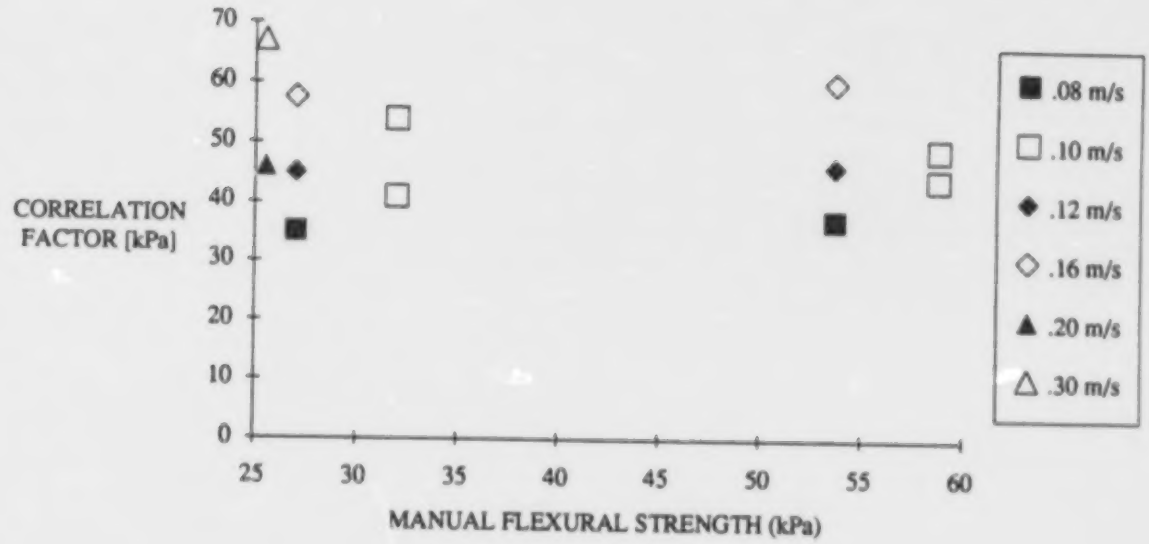
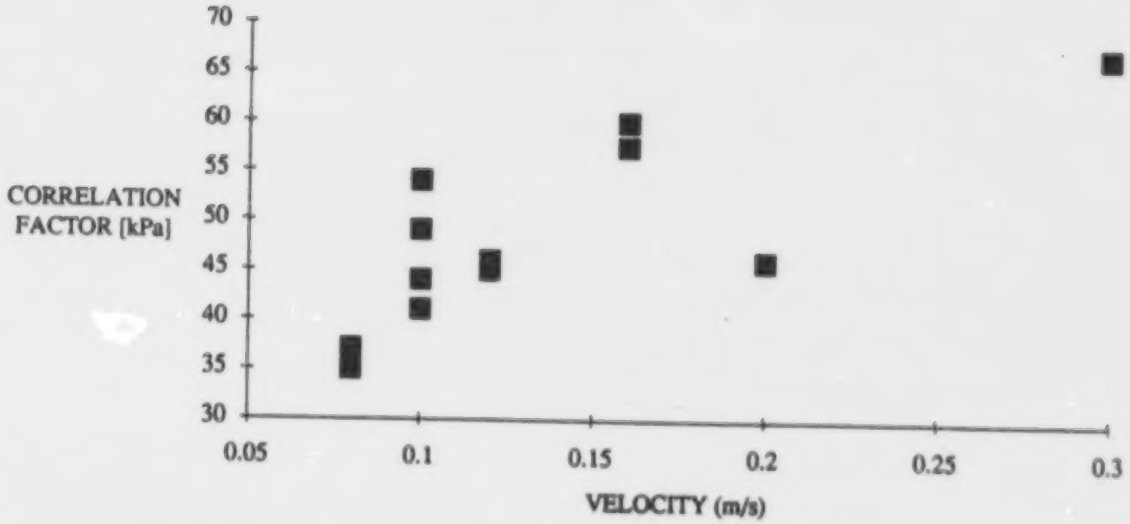


FIGURE 6.4
FLEXURAL STRENGTH CORRELATION FACTOR
vs VELOCITY



6.2.3 Shear Strength

The forces recorded from the shear plate were more erratic than the flexural forces as shown in figure 6.5 which illustrates the same area of ice as figure 6.1. To develop an analysis of the shear data it was necessary to include a series of conditions and criteria on the data to extract those portions which had a clean, sustained force vs deflection curve. These portions were analyzed and the strength was calculated as described in Appendix 1. The reason the shearing force output was more erratic than the flexural force output is believed to be due to the more complex failure mechanism created by the shearing plate. This may, in part, be due to some crushing and flexural failure occurring at the shear plate and, possibly, some transient response of the INDEXER. Figure 6.5 presents about seven meters of data. To review the analysis the data set is expanded, using the "Zoom" function in the program, and Figure 6.6 presents about 0.5 m of data.

FIGURE 6.5
SHEAR FORCE vs TANK POSITION

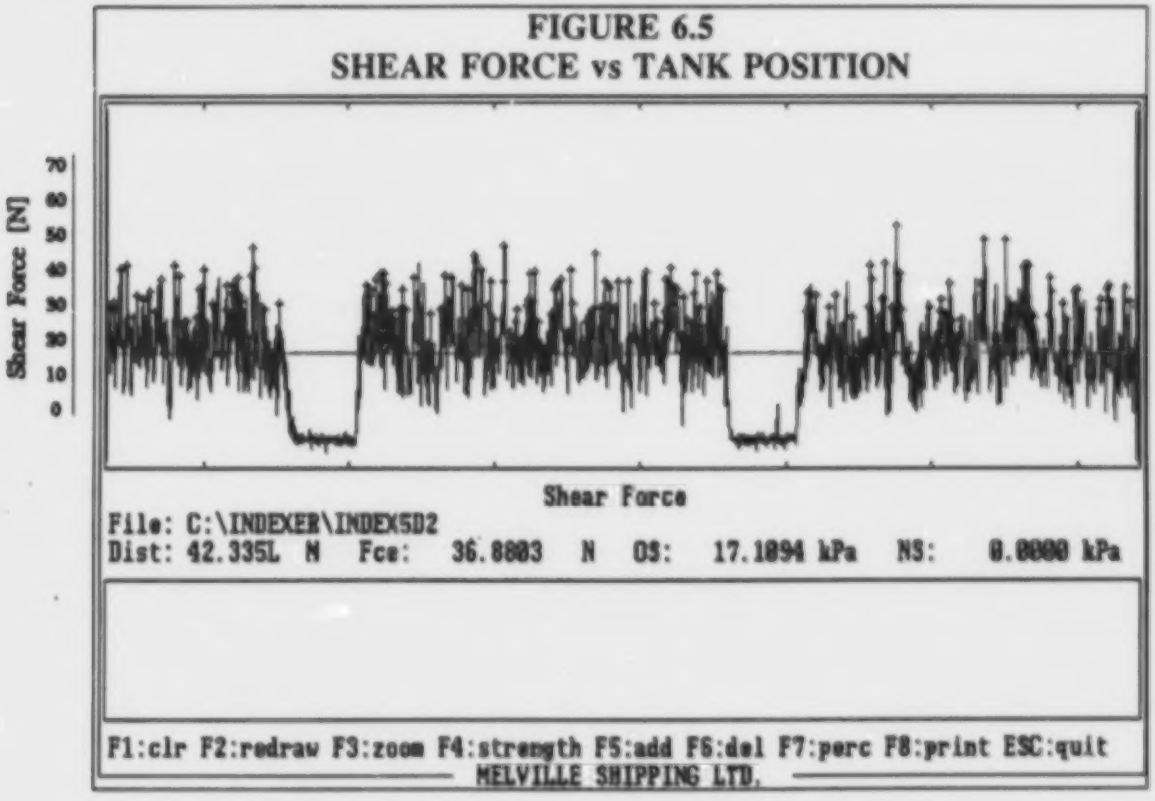


FIGURE 6.6
SHEAR FORCE vs TANK POSITION

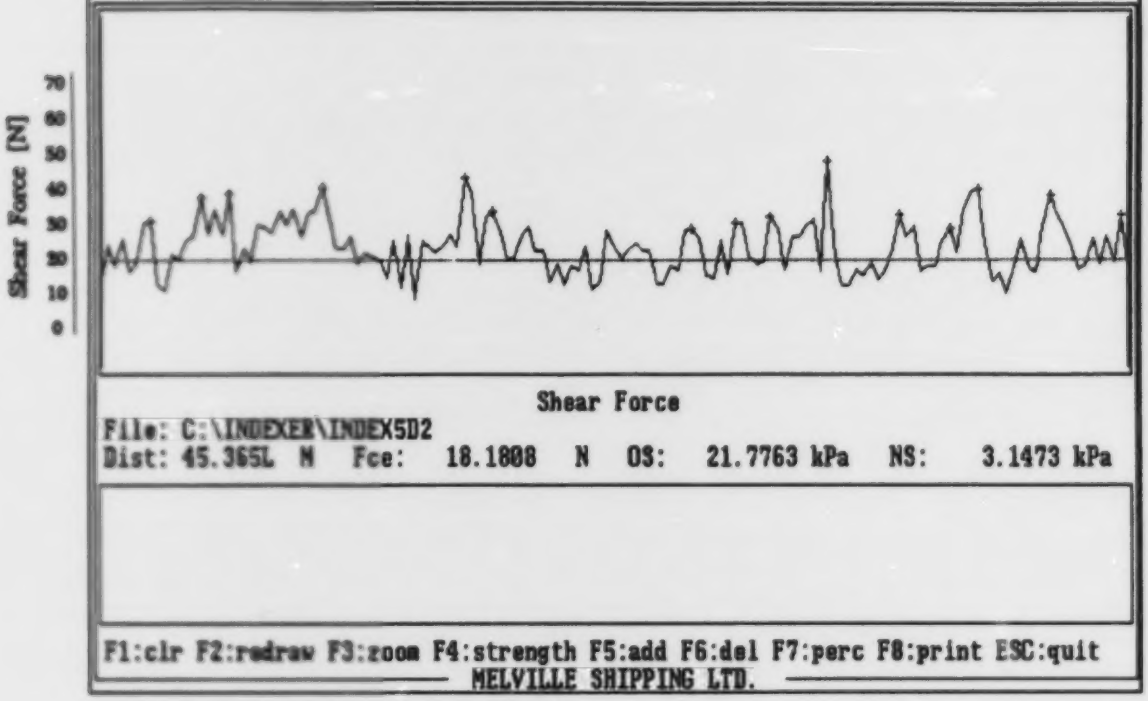
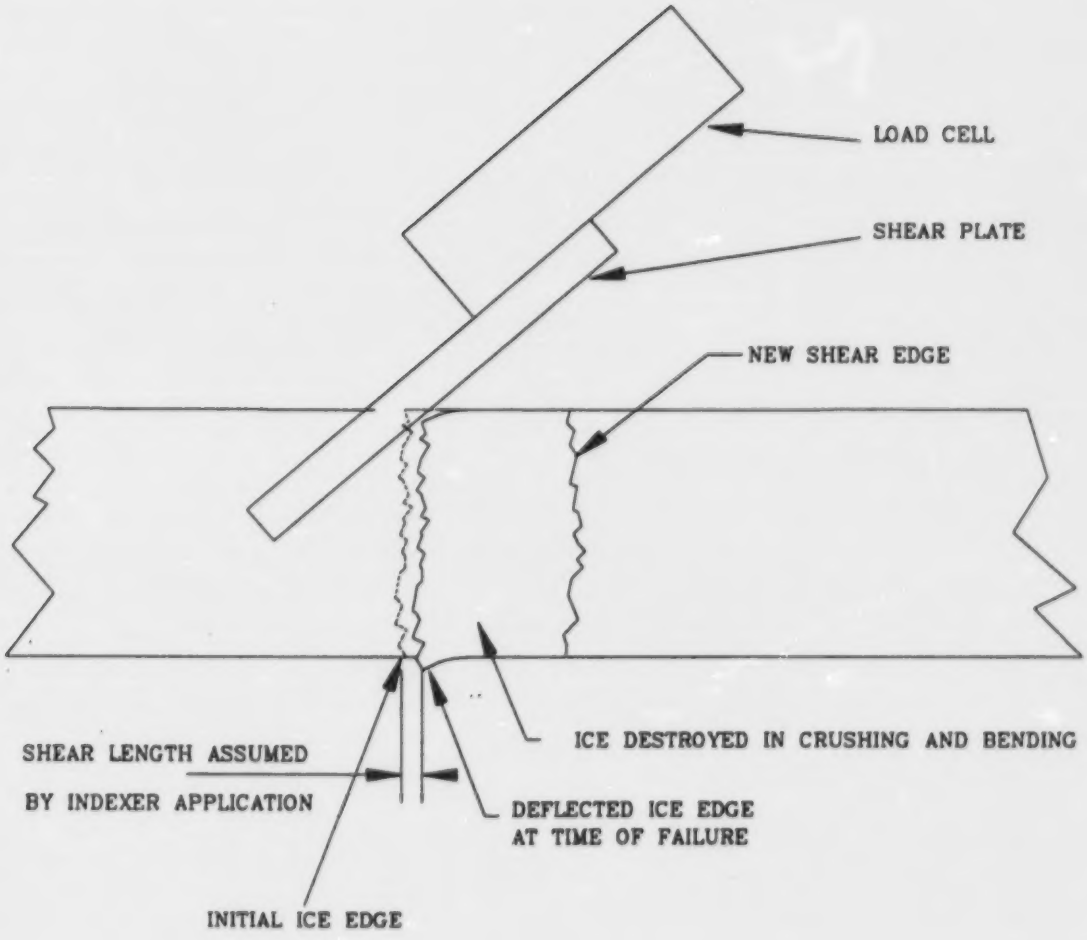


Figure 6.6 presents shear force data with the selected forces identified with crosses. The calculation of shear stress based on the peaks and their associated slopes were derived after a review of the physical process at the shearing plate. Figure 6.7 illustrates the shearing plate in section. Based on observations during the test and the force output, the shearing plate is believed to fail the ice in a number of steps. The first step is at initial impact between the shear plate and the upper surface of the ice sheet. Following initial contact, the ice edge is deflected down and shear is induced. This is considered to be the cleanest occurrence of shear during the interaction. Once this has taken place there is a succession of smaller shear failures and possibly some bending and crushing.

Based on this analysis it was elected to calculate the shearing strength using the shear force calculated as the difference between the force peak and the associated force "valley" occurring directly prior to the peak. The length is taken as the distance travelled between these two forces. This is considered to be representative of the initial shear failure discussed above. Although an analysis of the data tends to indicate that the actual shear failure length is larger, it was decided not to attempt to

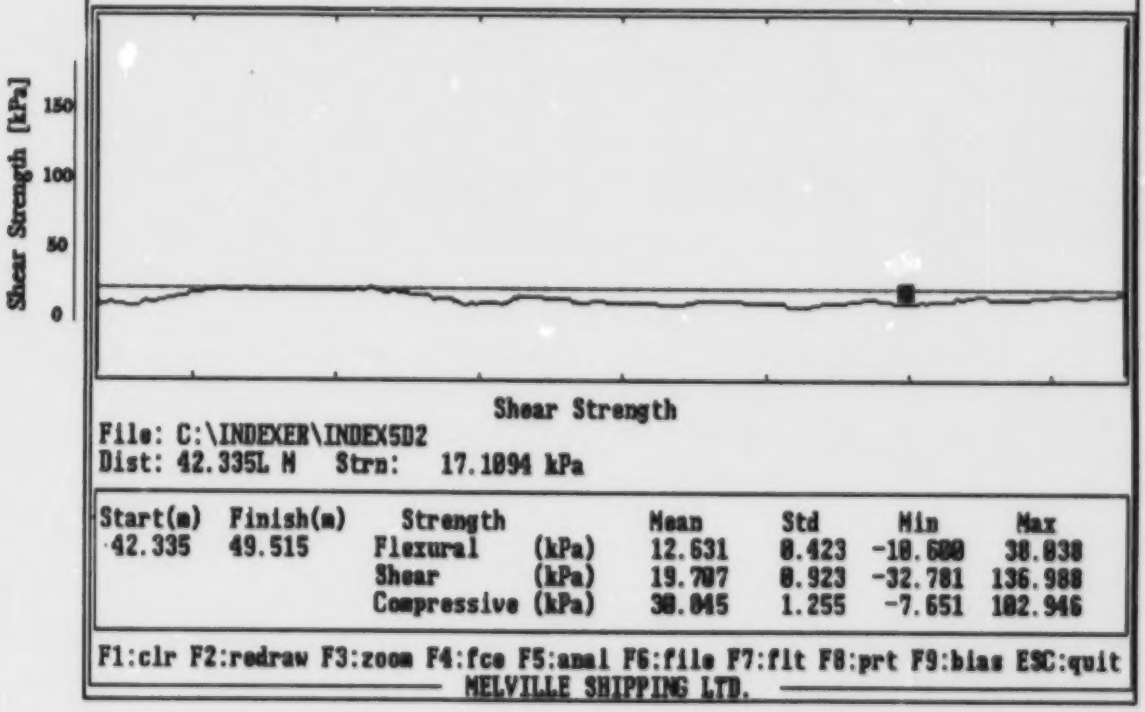
FIGURE 6.7
INDEXER SHEAR FAILURE
DIAGRAMATIC OF FAILURE MECHANISM



correct for this in the analysis formula. Instead, the resulting difference in calculated strength was absorbed in the INDEXER correlation and again this correlation is calculated for every thickness, strength and carriage velocity.

Figure 6.8 illustrates the filtered shear strength over the same area as illustrated in Figure 6.5. Figure 6.9 illustrates the correlation factor for shear strength plotted against the manually recorded flexural strength for the 65 mm ice sheet. It was elected to use the manual flexural strength because of the limited manual shear strength available. It can be seen from the figure that data was only available for a limited number of manual strengths in the 25 and 57 kPa ranges. As with the flexural strength correlation factor shown on figure 6.3 there does not appear to be a significant relationship between the correlation factor and strength.

FIGURE 6.8
SHEAR STRENGTH vs TANK POSITION


Shear Strength [kPa]
150
100
50
0
Shear Strength
File: C:\INDEXER\INDEX5D2
Dist: 42.335L M Strn: 17.1894 kPa
Start(m) Finish(m) Strength Mean Std Min Max
42.335 49.515 Flexural (kPa) 12.631 8.423 -18.600 38.838
Shear (kPa) 19.707 8.923 -32.781 136.988
Compressive (kPa) 38.045 1.255 -7.651 102.946
F1:clr F2:redraw F3:zoom F4:fce F5:anal F6:file F7:flt F8:prt F9:bias ESC:quit
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The INDEXER calculated shear strength was most dependent on the carriage velocity. The correlation as a function of velocity is presented in Figure 6.10. The data points represent a range of different strengths. It may be seen from the figure

FIGURE 6.9
SHEAR STRENGTH CORRELATION FACTOR
vs ICE SHEET STRENGTH FOR THE 65 mm ICE SHEET

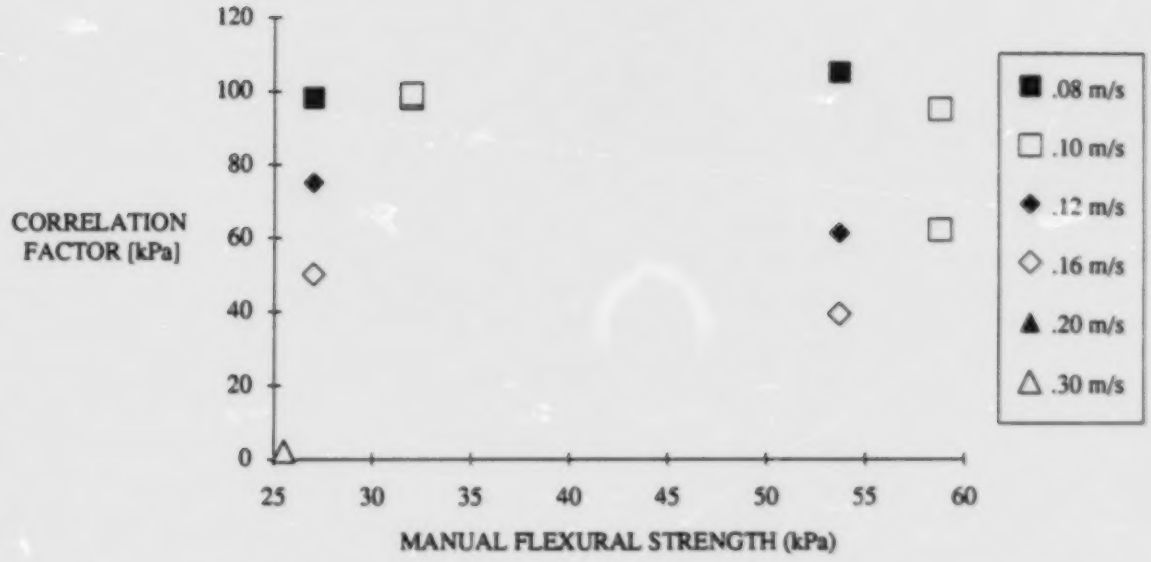
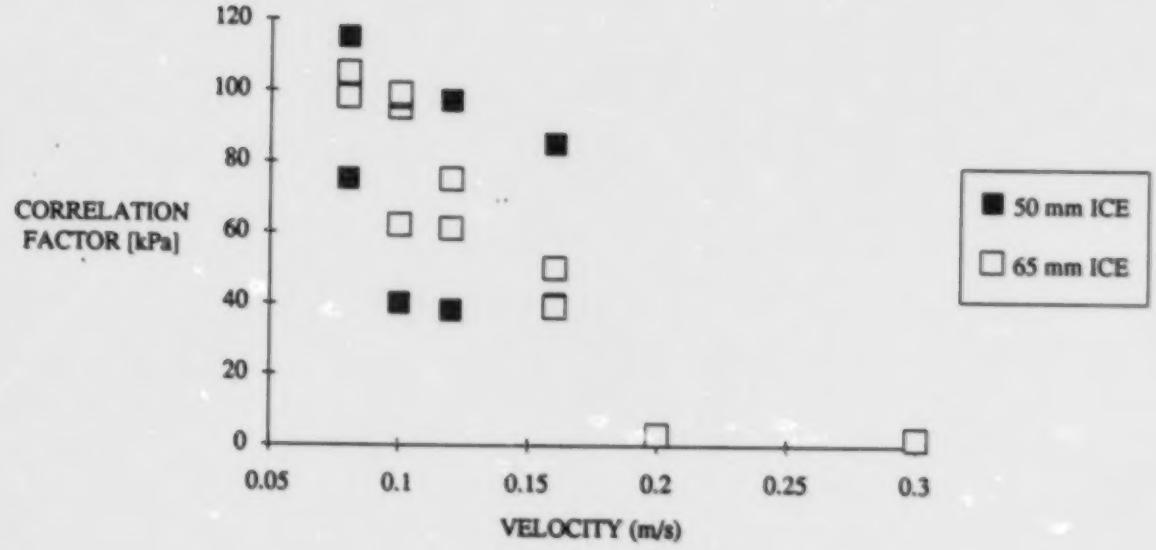


FIGURE 6.10
SHEAR STRENGTH
CORRELATION FACTOR vs VELOCITY

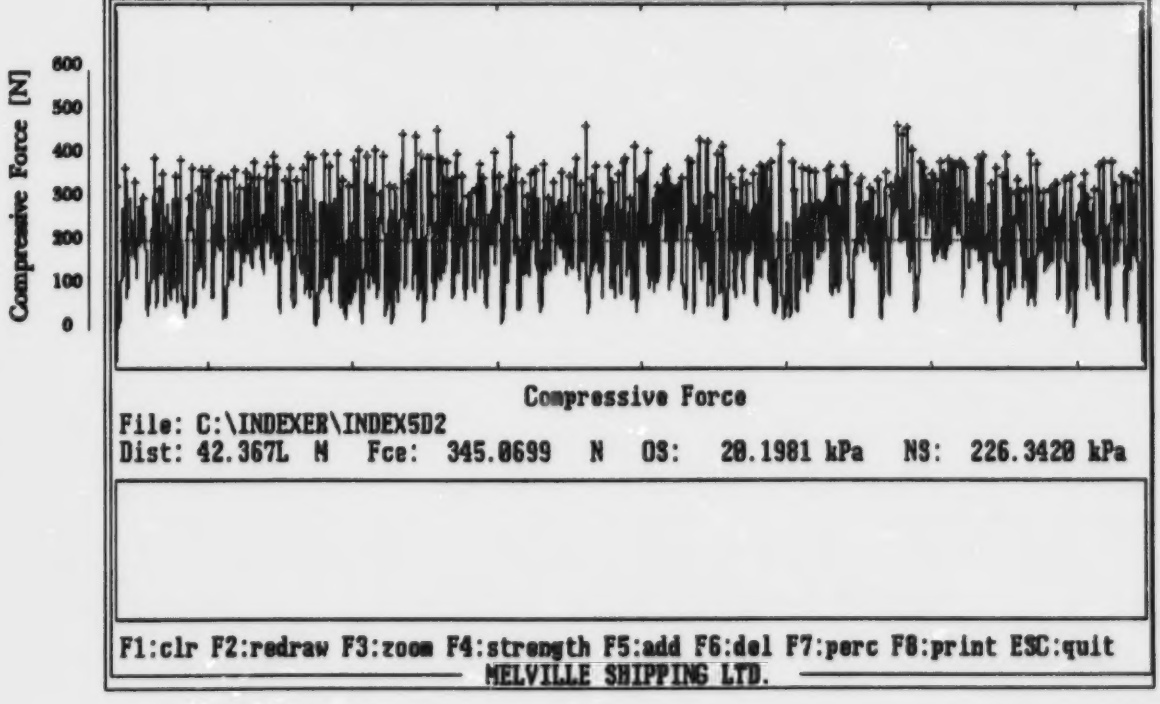


that there appears to be a sharp decrease in the correlation offset as velocity increases. Reviewing the force output this is believed to be due to the slope of the force vs deflection curve becoming shallower resulting in a greater length being used in the shear strength calculation while the actual shear area may not be changing. The absolute force peak does not appear to change significantly with speed.

6.2.4 Compressive Strength

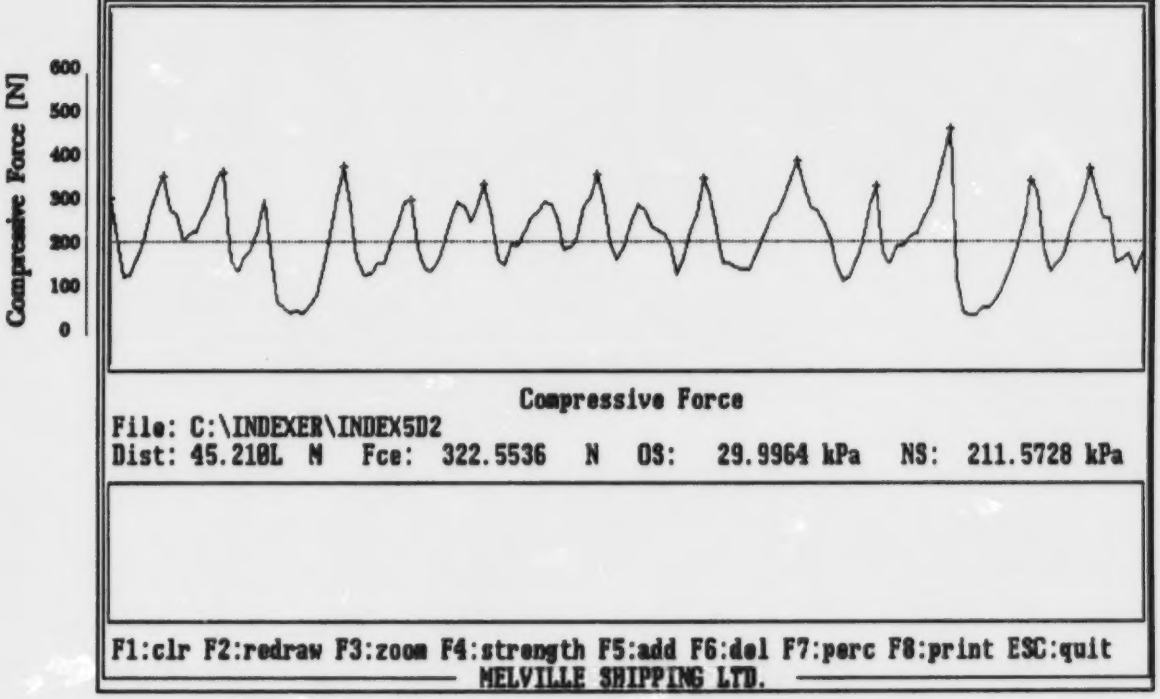
The time history of the compressive force output was typified by large force peaks occurring at a frequency of approximately 1 hz, depending on the carriage velocity. The compressive force as a function of tank position is shown in Figure 6.11 for about a 7.0 m length. This output may be compared with the flexural and shear strength data from Figures 6.1 and 6.5.

FIGURE 6.11
COMPRESSIVE FORCE vs TANK POSITION



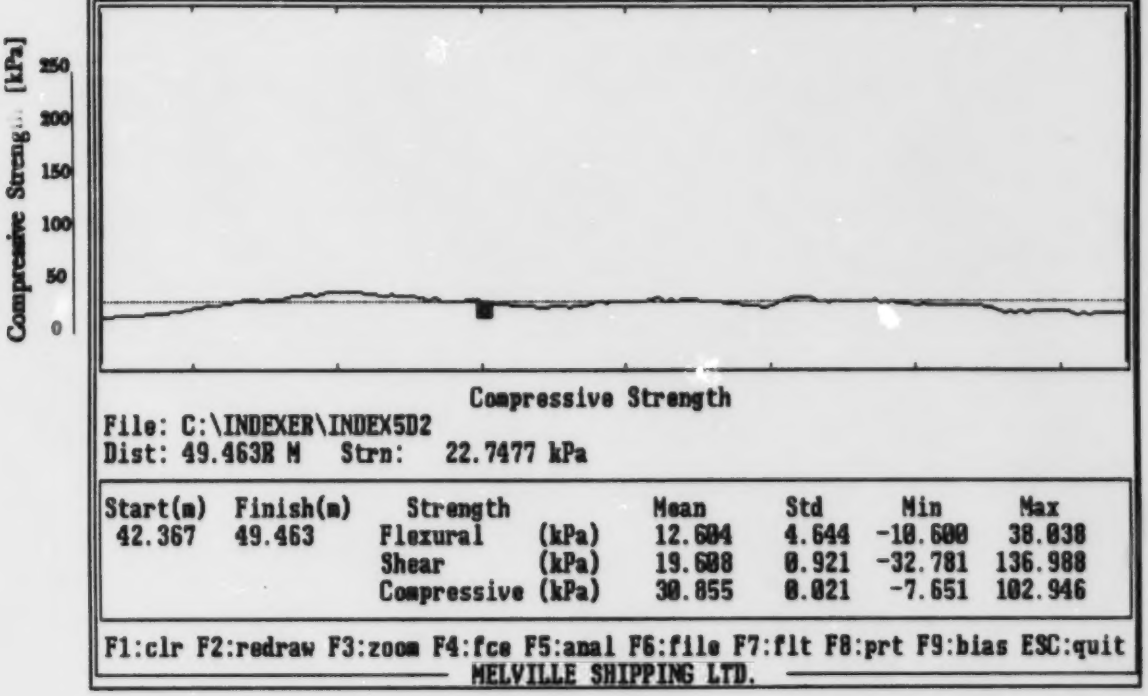
The output from the crushing plate was relatively clean since the noise and transient vibrations were small in comparison to the peaks. The data may be expanded, as shown in Figure 6.12 to review the output in more detail. Figure 6.12 represents about 0.5 m of data. The peaks are selected by the INDEXER software application and the strength is calculated based on the thickness of the ice and the penetration of the crushing plate. The detailed calculation is described in Appendix 1.

FIGURE 6.12
ENLARGED COMPRESSIVE FORCE vs TANK POSITION



The compressive strengths calculated from the INDEXER are shown in Figure 6.13 and are considerably higher than the corresponding manual strengths. This is believed to be due to the confined nature of the ice during the INDEXER tests compared to the uniaxial, unconfined, samples tested using the manual test equipment. Again, no modification was made to the formula to reflect this difference.

FIGURE 6.13
COMPRESSIVE STRENGTH vs TANK POSITION



As with the flexural and shearing plate output there was no significant influence of either ice thickness or strength on the INDEXER correlation factor. Figure 6.14 illustrates the INDEXER correlation vs. flexural strength relationship. The compressive strength correlation is shown as a function of carriage velocity in Figure 6.15. It may be seen from the figure that the offset generally decreases with increasing velocity.

FIGURE 6.14
CRUSHING STRENGTH CORRELATION FACTOR
vs ICE SHEET STRENGTH FOR THE 65 mm ICE SHEET

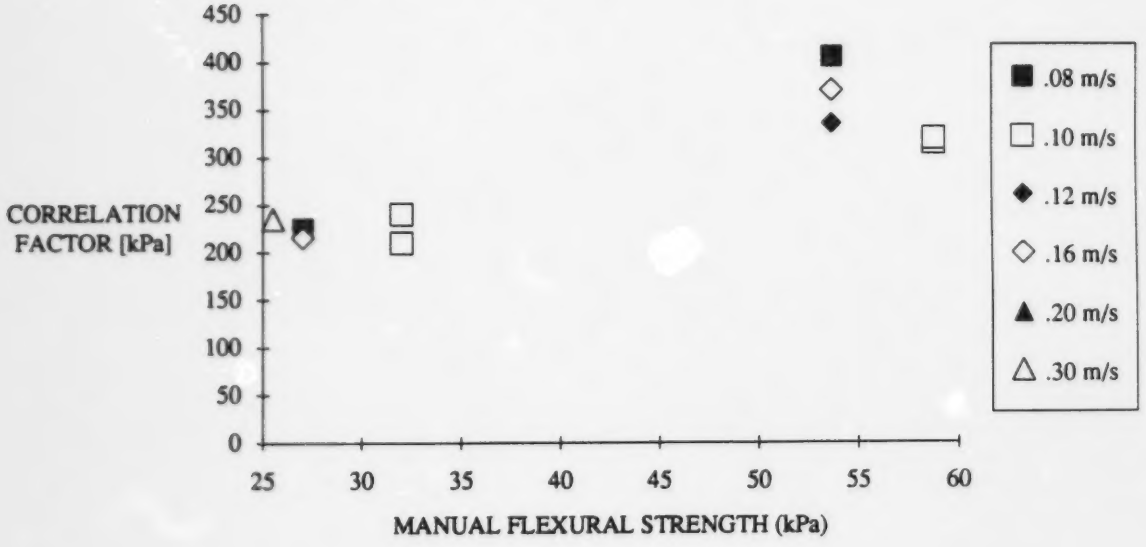
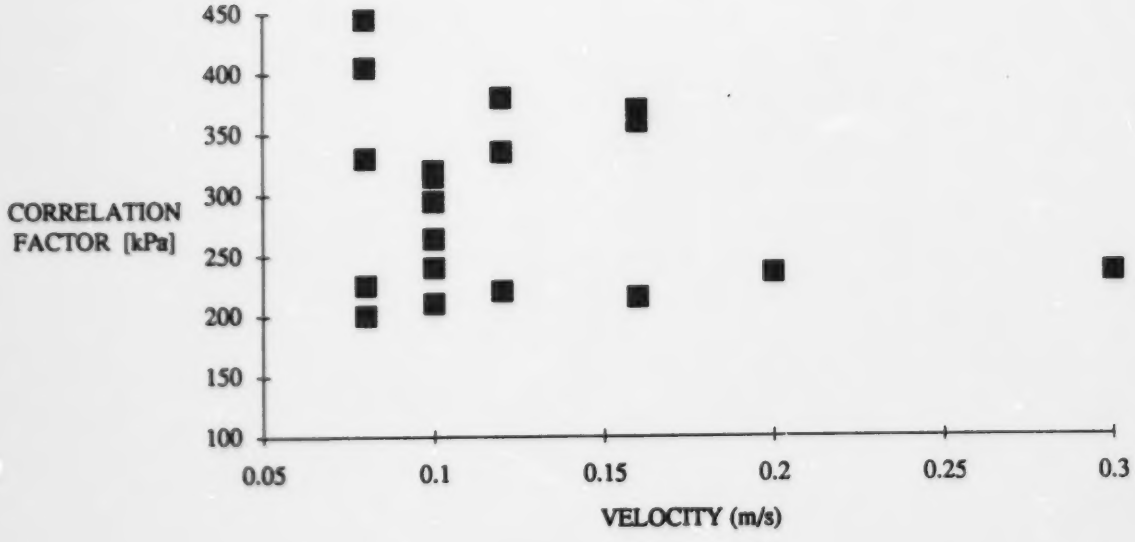


FIGURE 6.15
CRUSHING STRENGTH CORRELATION
FACTOR vs VELOCITY



6.3 Test Analysis

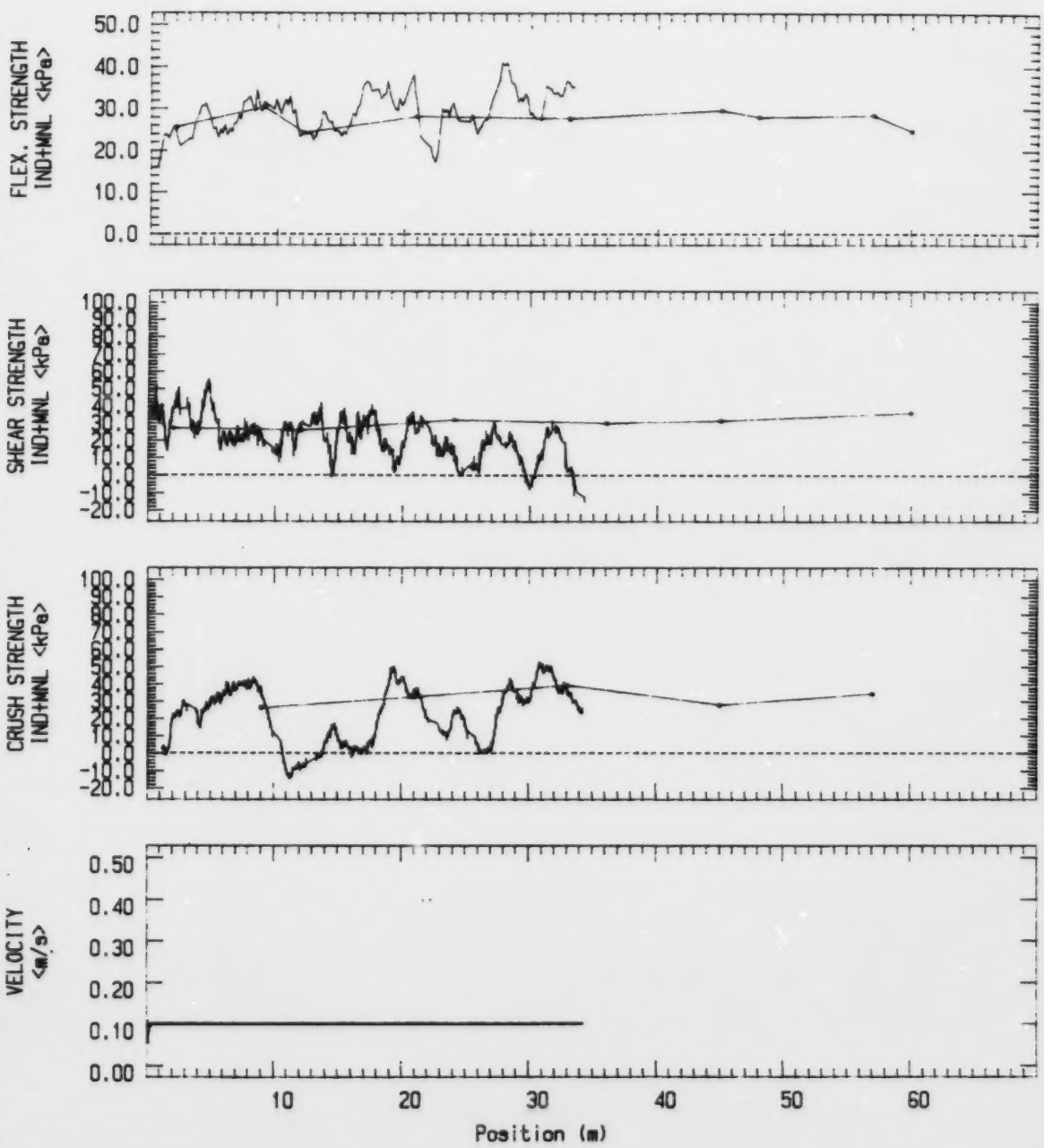
Figures 6.16 and 6.17 illustrate example INDEXER outputs for a test run. Each data set has been filtered with a moving average filter that approximates a width of about 1.0 m and applied with a bias offset. It can be seen from this data set that the variation in the INDEXER output is significantly higher than the manual force records. One reason for this was considered to be the format of the bias offset which was originally an addition or subtraction from the INDEXER strength series. An alternative procedure would be to apply a multiplier as the offset. To investigate this option, the application was modified and Figures 6.18 and 6.19 illustrate the same data with the multiplier in lieu of the constant offset.

This result clearly generated more consistent correlation between the INDEXER and manual data sets. Unfortunately there was insufficient time to pursue this correlation procedure within the scope of this project.

It may be noted that the manual, and to some extent the INDEXER, tests did not highlight any significant strength variations along the length of the ice sheets. Although a primary reason for developing the INDEXER was to permit the collection of shear and compressive data, it was also speculated that the strength could vary along the length of the tank and that the INDEXER would identify these variations. This is not clear from the INDEXER tests but was highlighted during recent tests conducted in early 1988 and 1989 for the TDC (Baker 1990, 1988). Figure 6.20 illustrates the resistance vs. speed relationship for two tests, the Beam series and Midbody series, conducted with the same model of the MV ARCTIC in nominally identical ice conditions.

Although the resistance values, which have been corrected for variations in ice thickness, strength and friction coefficient, show very close correlation for the three low speeds, there is clearly a significant difference between the data from the high speed tests. Following this result the data was closely analyzed but no clear reason could be established for the difference. The only explanation that could be supported was that the ice sheet properties, recorded with the manual test procedures, were not representative of the ice in which the model was tested. This theory was supported by reviewing the ice sheet properties along the remainder of the tank. Assuming that the ice properties changed uniformly from the low speed tests to the higher speed test, it was possible to estimate a new ice strength for the high speed section. Using this value resulted in a much closer correlation between the two series of tests.

FIGURE 6.16
INDEXER OUTPUT AND CORRELATION WITH MANUAL TESTS



INDEX-5A1 65mm> 8-SEP-1989 11:37:16

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FIGURE 6.17
INDEXER OUTPUT AND CORRELATION WITH MANUAL TESTS

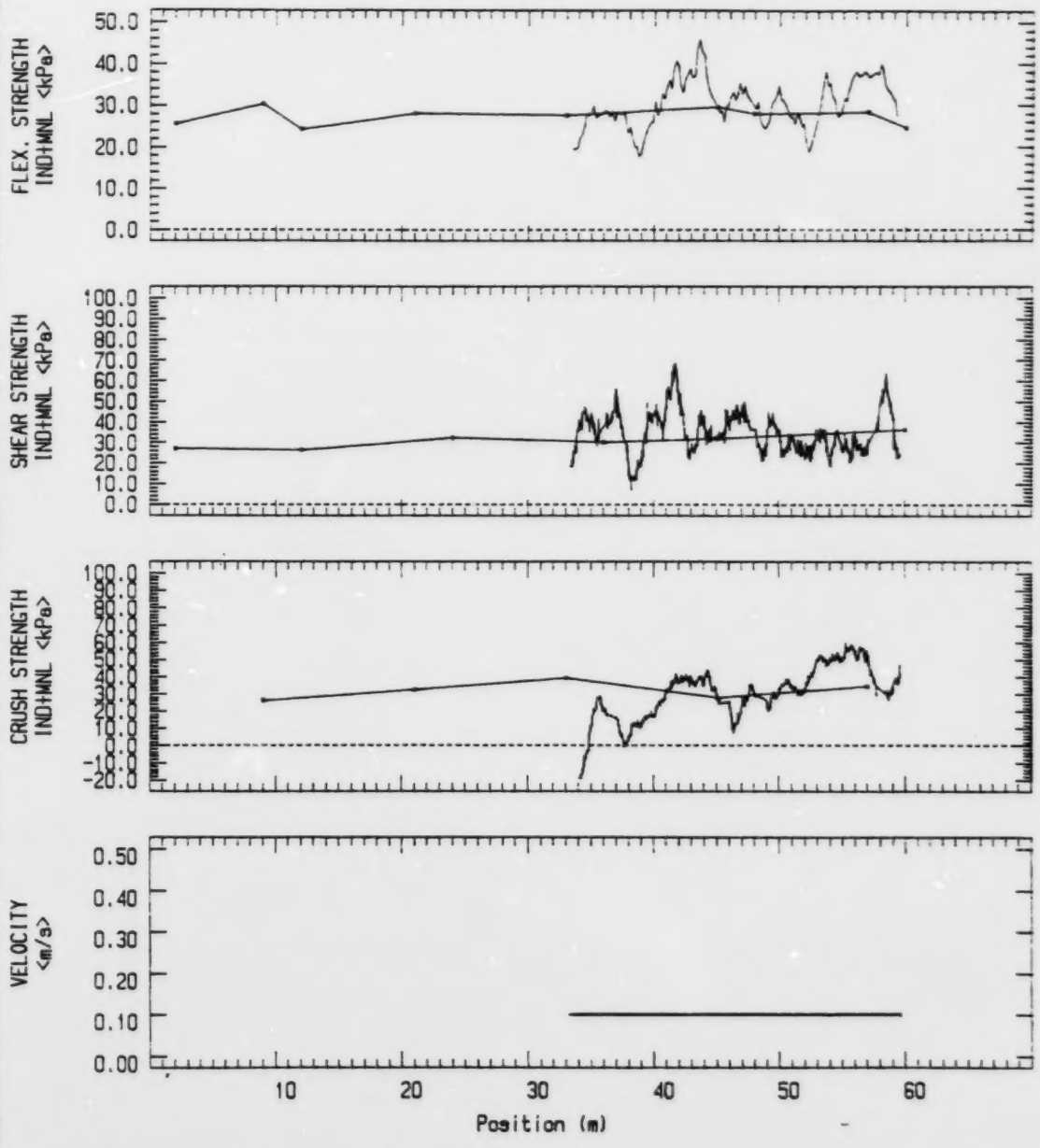
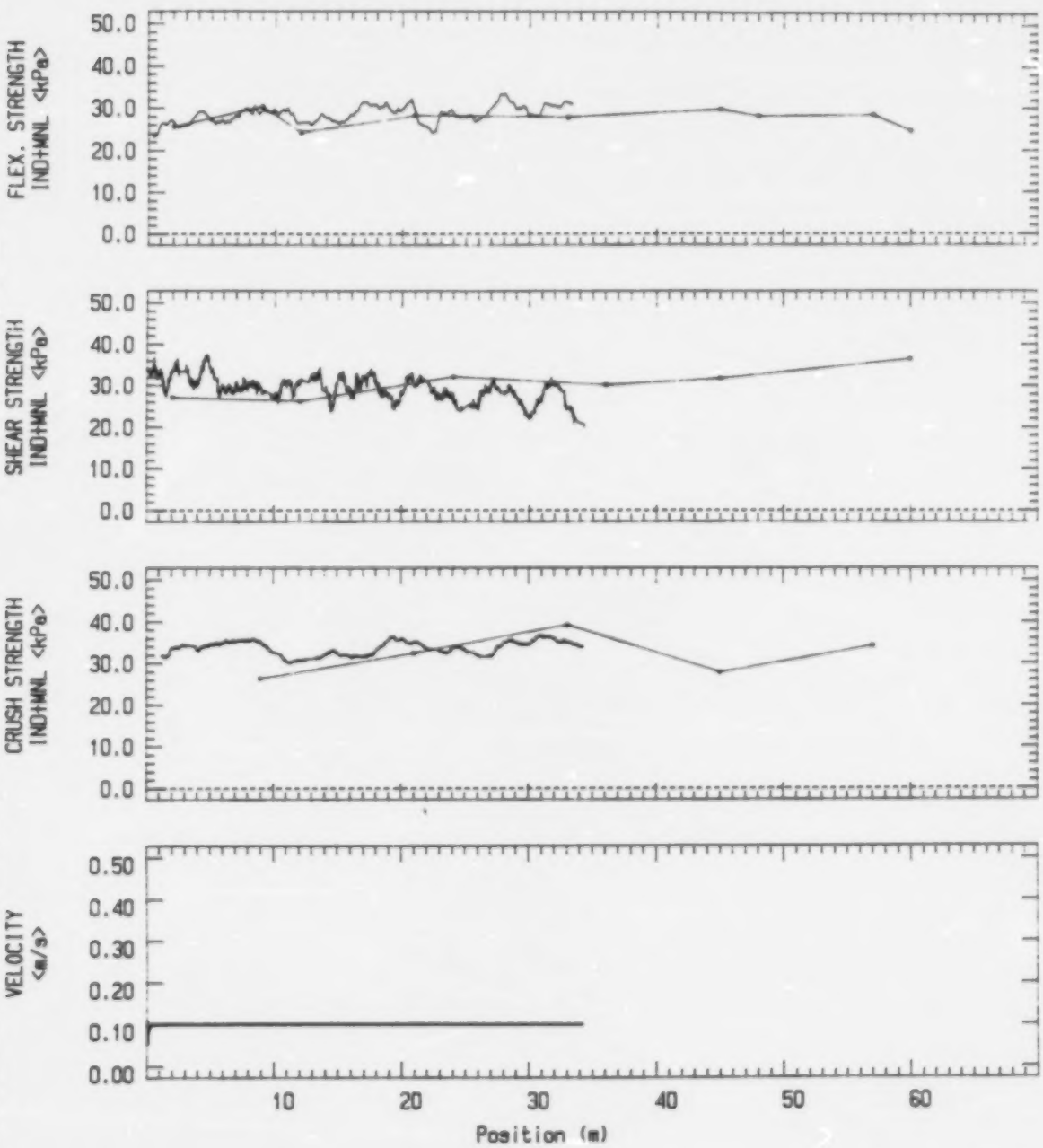


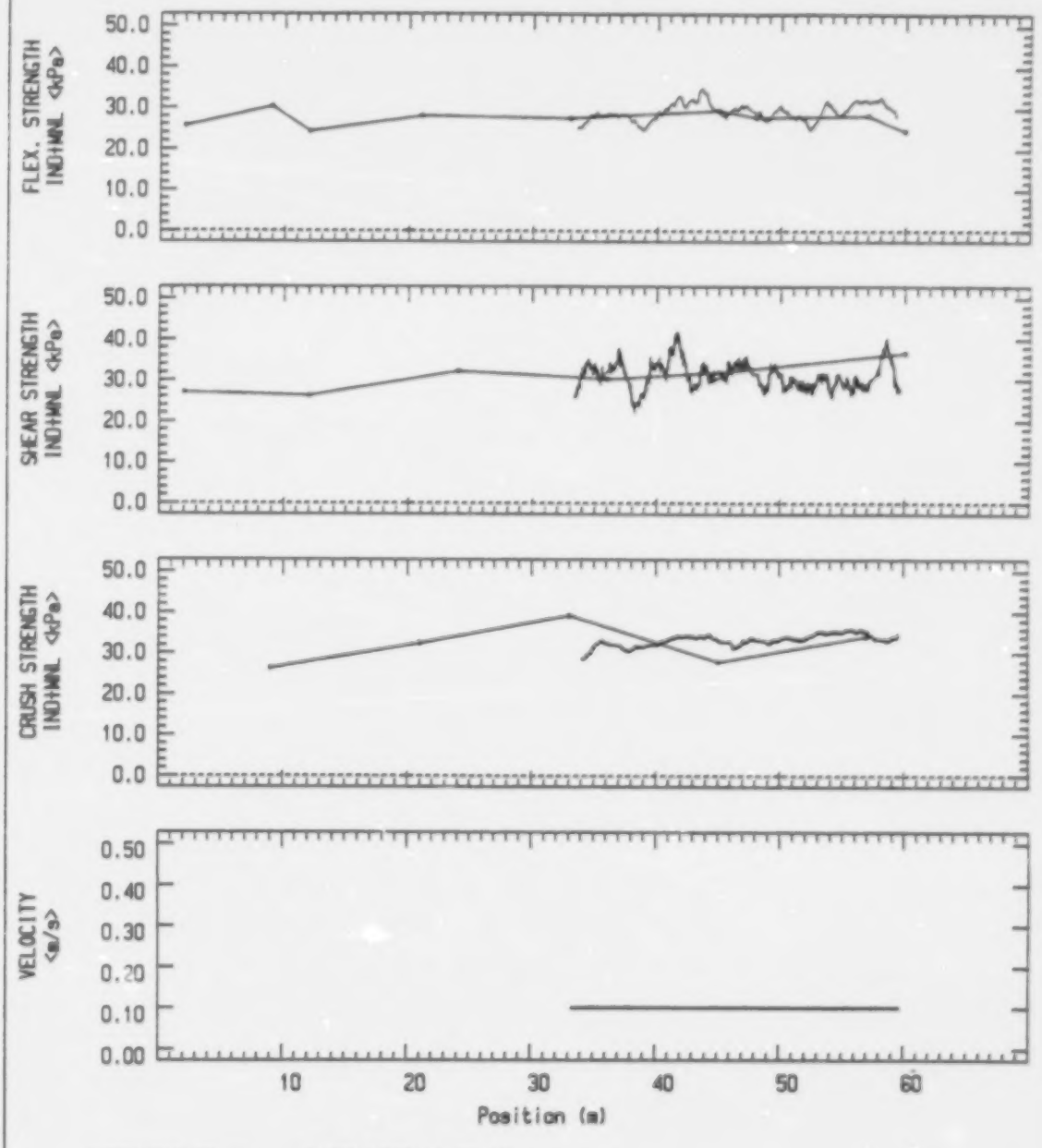
FIGURE 6.18
INDEXER OUTPUT AND CORRELATION WITH MANUAL TESTS



INDEX-5A1 65mm> 8-SEP-1989 11:37:16

MELVILLE SHIPPING LTD.

FIGURE 6.19
INDEXER OUTPUT AND CORRELATION WITH MANUAL TESTS

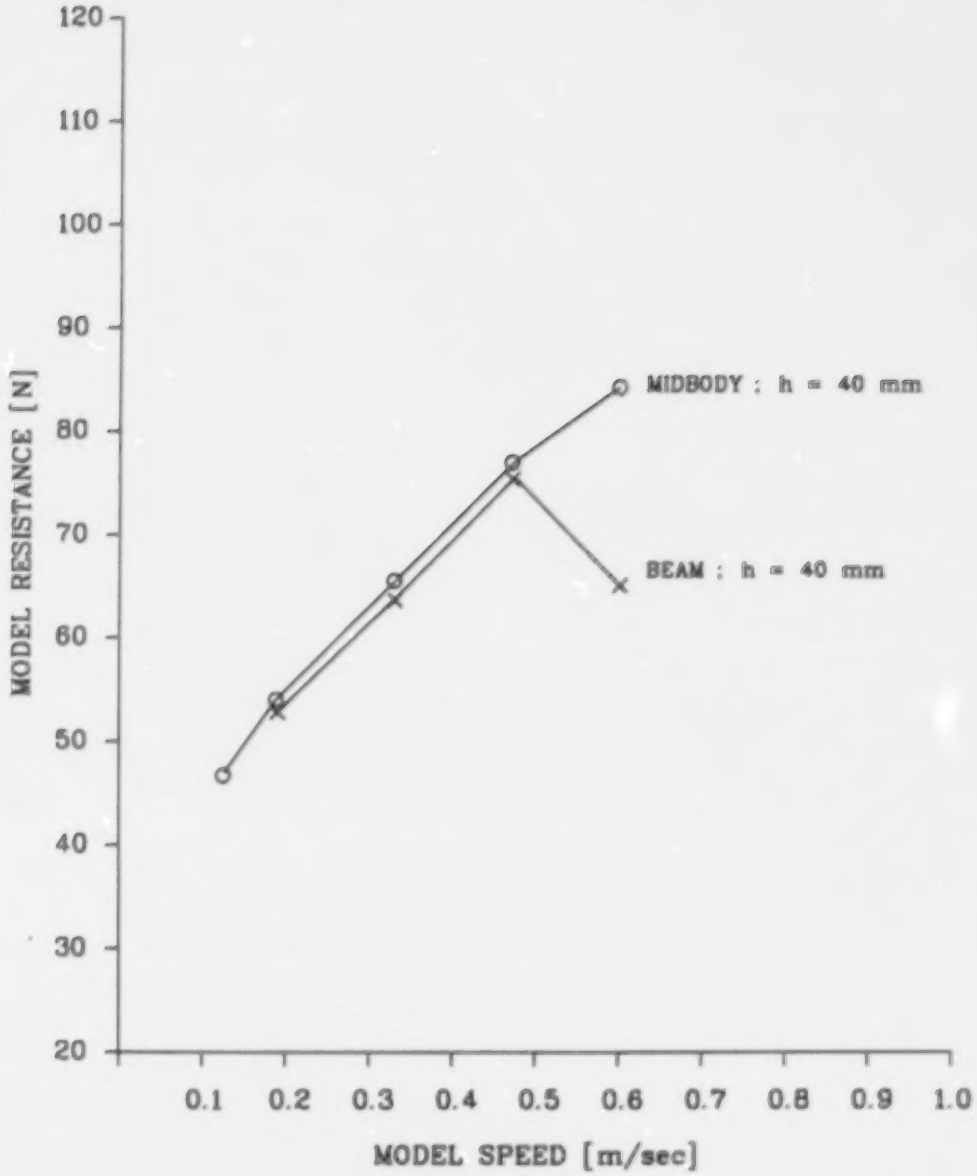


INDEX-5A2 65mm> 8-SEP-1989 11:37:16

MELVILLE SHIPPING LTD.

FIGURE 6.20

COMPARISON BETWEEN TWO INDENTICAL MODEL TESTS IN THE SAME NOMINAL ICE CONDITIONS



Target Ice Thickness = 40 mm
Target Ice Strength = 16.67 kPa
Target Friction Coefficient = 0.06

7. CONCLUSIONS

The basis for performance predictions from model tests is the ability of the model ice to simulate the characteristics of full scale ice. This is not possible with current ice melt additives. Recognizing this compromise with model tests in ice, a series of correlation factors have been developed by the ice tank operators and users to correct the model scale resistances to full scale. An important factor in this process is a clear definition of the mechanical properties of the model ice. This is currently achieved with a limited number of manual ice tests that are usually based on the flexural strength of the ice alone. The INDEXER has been shown to have the potential to comprehensively measure the mechanical properties of the model ice with respect to the flexural, shearing and crushing modes.

The conclusions of the INDEXER project may be summarized as;

a) The INDEXER has been redesigned to reflect operational problems experienced with the original design. This redesign has included a new instrumentation and ice cutting system.

b) A new support frame for the INDEXER has been constructed at the Institute for Marine Dynamics that will permit the INDEXER to be used effectively in conjunction with model tests.

c) A water jet system for cutting the ice has been successfully tested and integrated into the INDEXER design.

d) For the INDEXER to be successful it was necessary to generate consistent breaking mechanisms so that the force output and resultant ice strengths could be compared from one part of the tank to another or one ice sheet to another. The INDEXER has been tested in a series of ice sheets and the observations and results indicate that the design has fulfilled this requirement.

e) A computer application has been developed that transforms the INDEXER force time history output to ice strength as a function of INDEXER position in the ice tank.

f) The ice strength output from the computer program has been compared to the manual measurements made during the tests. The results of the comparison

yield a correlation factor, or offset, which may be applied to the INDEXER output to yield representative ice strengths along the ice tank.

g) The correlation factors for each INDEXER test have been compared as functions of INDEXER speed, ice thickness and ice strength. The correlation factors were found to be strongly dependent on speed.

h) The improved functionality of the redesigned INDEXER has demonstrated that the device can be easily incorporated into the standard model testing procedure adopted by IMD.

i) The additional ice strength information provided by the use of the INDEXER will significantly improve the capability of model ice tank users to accurately predict the performance of ice transitting ships.

8. RECOMMENDATIONS

The INDEXER program is considered to be a success with significant improvement made to the INDEXER design, the INDEXER support platform and the testing procedure. However, there are a number of areas that are considered to require more work to fully develop the INDEXER concept. These may be summarized as follows.

a) Although a series of tests were conducted on the INDEXER, they were not sufficient to fully develop the relationship between the strength correlation factor and the INDEXER speed, tested ice thickness and ice strength. It is considered that some additional analysis of the completed tests and a series of additional tests will be required to improve this correlation and determine how it varies with these variables.

b) Although a sophisticated data analysis program has been developed to analyze the INDEXER output data, the current data acquisition system on the IMD ice tank carriage does not permit this analysis to be done immediately on the carriage. An integrated data acquisition system and automatic data analysis system would permit a more direct analysis of the model ice strength on the carriage.

c) The current deployment of the INDEXER is manual using a hand cranked jack and manually deployed back stays. Realistically, if the unit is to be used by the tank personnel on a regular basis it must be capable of being deployed automatically. This can be simply achieved using a remote control system based on the computer. A total INDEXER system would include an automatic deployment of the INDEXER to the prescribed height, a data collection system and an integrated data analysis system.

d) The primary objective of the INDEXER is to measure the mechanical properties of model ice to permit the accurate performance prediction of model ice breaking ships. The procedure currently used to correct the model ice mechanical strength to full scale is based on the flexural strength. However it is well known that the shear and crushing strength of the ice also have an influence on model hull resistance. A method must be developed therefore to establish the relationship between the shearing and crushing strength of model ice and the resistance. Based on this relationship it will be possible to correct model resistance for these strength properties in addition to the flexural strength.

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APPENDIX 1

PROGRAM DOCUMENTATION

for the

ICE INDEXER Software Package

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Ottawa, Ontario
K1R 7S8

June 1989

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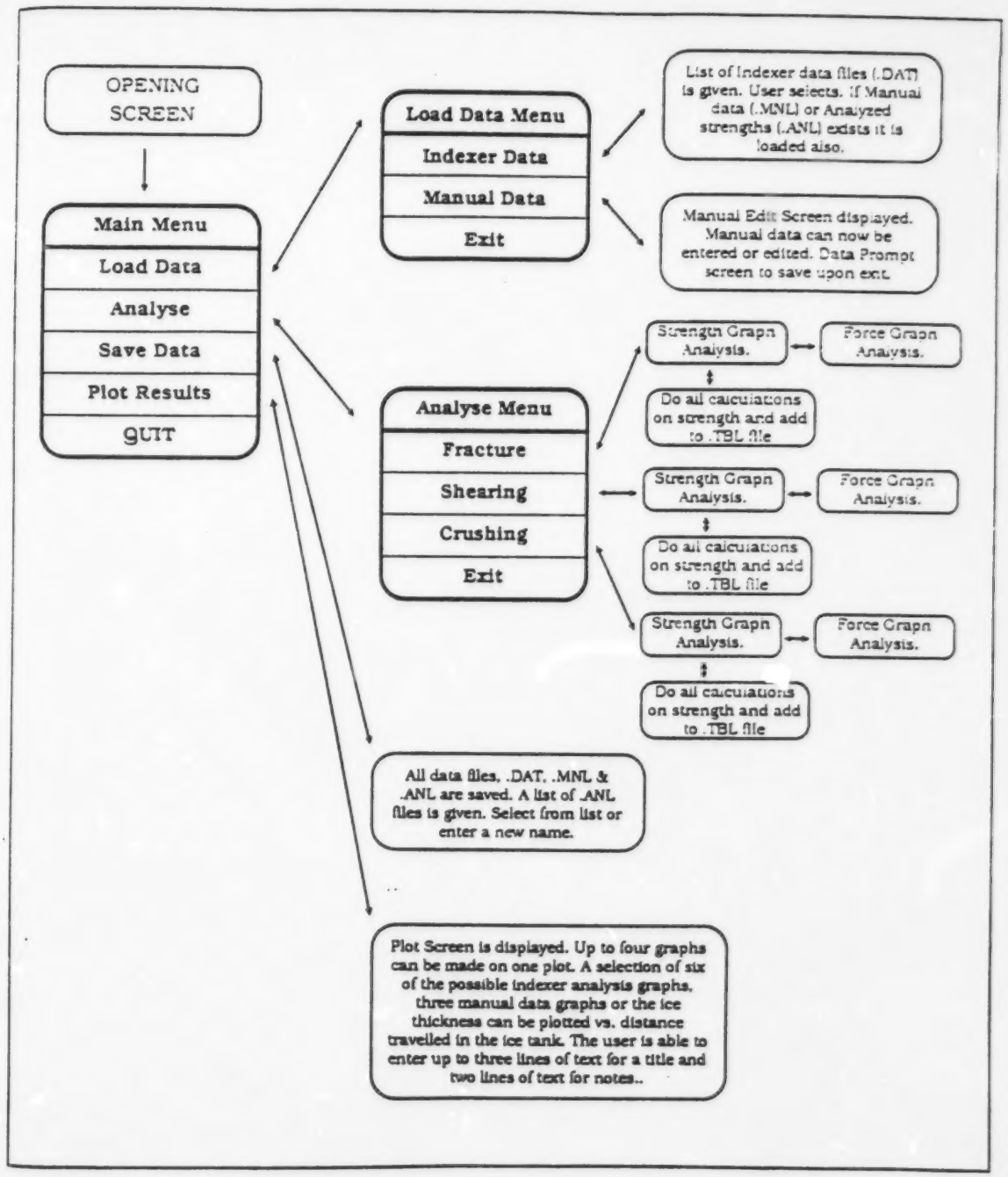
1.0 Introduction

The software application is a sophisticated data analysis and plotting tool for use with the ice strength INDEXER developed by Melville Shipping Ltd and the Transportation Development Centre (TDC). The application consists of a series of analysis functions which are used on the output from the INDEXER and permits the user to develop a complete definition of the subject ice sheet in terms of the flexural, shearing and crushing strength of the ice.

The application is illustrated in figure 1.1 as a flow diagram and may be divided into three main parts, Data Input, Data Analysis and Data Plotting. The following application manual describes each component in detail and the associated user instructions.

FIGURE 1.1

INDEXER APPLICATION FLOW DIAGRAM


OPENING SCREEN
Main Menu
Load Data
Analyse
Save Data
Plot Results
QUIT
Load Data Menu
Indexer Data
Manual Data
Exit
List of Indexer data files (.DAT) is given. User selects. If Manual data (.MNL) or Analyzed strengths (.ANL) exists it is loaded also.
Manual Edit Screen displayed. Manual data can now be entered or edited. Data Prompt screen to save upon exit.
Analyse Menu
Fracture
Shearing
Crushing
Exit
Strength Grapn Analysis.
Force Grapn Analysis.
Do all calculations on strength and add to .TBL file
Strength Grapn Analysis.
Force Grapn Analysis.
Do all calculations on strength and add to .TBL file
Strength Grapn Analysis.
Force Grapn Analysis.
Do all calculations on strength and add to .TBL file
All data files, .DAT, .MNL & .ANL are saved. A list of .ANL files is given. Select from list or enter a new name.
Plot Screen is displayed. Up to four graphs can be made on one plot. A selection of six of the possible indexer analysis graphs, three manual data graphs or the ice thickness can be plotted vs. distance travelled in the ice tank. The user is able to enter up to three lines of text for a title and two lines of text for notes..

2.0 System Requirements

The minimum system requirement for the application are as follows:

- IBM PC/XT/AT or compatible with 640 KB of memory
- 2 floppy disk drives, or 1 floppy disk and 1 hard disk
- CGA, EGA or VGA display
- MS-DOS 3.0 or higher
- Epson FX compatible printer
- Roland DXY 980

3.0 Program Memory Specifications

The four channels of raw force data, Carriage Speed, Bending Force, Shearing Force and Crushing Force are loaded into the application from an ASCII (American Symbolic Code for Information Interchange) file. The application then offers the user to convert this format to Binary for more compact disc storage. Each sampled record is 10 bytes is size and is divided based on the following format:

- Distance: A 4 byte floating point number, in mm. The distance is calculated from the speed (using an integration) versus time relationship.
- Forces: Three x 2 byte integer number, the force is calculated from the conversion factors supplied in the INDEXER data file.

The program allows 17,500 samples (175,000 bytes) of raw force data. Sampling at 50 Hz yields 500 bytes/second and, together with a memory size of 175 K, will give a total sampling period of 350 seconds or 5.83 minutes.

The strength data, as calculated from the force data, is in the following format:

- Distance: A 4 byte floating point number, from above.
- Strength: A 4 byte floating point number.

This yields 8 bytes per record for each strength. The program allows for a maximum of 5,000 strength calculations per force channel (71.43 calculations per meter). This requires 120 K of memory.

The application requires 105 K for the program code and 64 K for near data. This results in a total memory requirement of 464 K of memory.

This approaches the maximum memory available to run a DOS program.

4.0 Software Description

Menus

In a menu the user may select an item using either one of the following two methods:

- Cursor keys up or down until the item is highlighted then pressing the cursor RIGHT (CRRT) key or the ENTER key; or
- If the desired item has a letter enclosed in square brackets, [], the user may press the enclosed letter key and this item will be selected.

The user may move to the previous menu by using one of the following two methods:

- Selecting the e[X]it item in the menu using the cursor keys, or
- pressing X, or
- pressing the cursor left key.

Entering Values

To enter a numerical value, or a text string, the user must press the RETURN or TAB key, otherwise, the old value will remain unchanged. The user may press the INSERT or DELETE key and they will function in the usual manner. The HOME key will move the cursor to the beginning of the field. The END key will move the cursor to the last character entered in the field.

Help

Help is obtained at any time by pressing the '?' key. A window will appear in the upper left corner with the information required. To exit the Help screen the user must press the space bar.

Function Keys

A list of function keys and their purposes are usually given at the bottom of the screen. As a standard, F1 will clear the field the user is currently in; F2 will recall a previous value; F9 will display the opening screen; and, F10 will display a window containing the date and time.

Filelist

When a list of files are presented to the user, for example while saving a file, a file name may be selected using the curser keys to highlight a file name and pressing Enter. If the file is not present, the user will be prompted to create a file in the case of file saving or must select a file from the from the list if loading a file. The application will permit the user to enter any file name for storage , however, if the file already exists the user will be asked if the file can be overwritten.

The program makes use of five different files. They are:

- The Raw data file in ASCII format that contains the speed and the forces from the three ice indexer plates. The filename will have the extension ".DAT".
- The Raw data file that contains the conversion factors, distance and three forces. This file will be in a Binary format to conserve disk space and reduce the time required to load the raw data. It is estimated that the

Binary file will be about 10 times smaller than the .DAT file. The filename will have the extension ".BIN".

- The Manual data file will contain ice sheet information collected manually and input by the user. The file will be in an ASCII format. The filename will have the extension ".MNL".

- The Analyzed data file will contain the analyzed strength data from each run as a function of distance. The file will be in ASCII format. The filename will have an extension ".ANL".

- The Table file will contain the results from selecting specific regions of the strength data and storing them to file. The data will be in ASCII format. The file must will have an extension ".TBL".

All files associated with a specific data file will have the same first eight characters but end with the appropriate extension characters.

Loading Data

Data can be loaded in one of two methods. Selecting "LOAD INDEXER ASCII", will load the original ASCII .DAT file, selecting "LOAD INDEXER BINARY", will load the analyzed ".ANL" files and the .BIN files.

Using the first method gives a list of all the '*.DAT' files contained within the current working directory. When a file from this list is selected, the program will first search for any "*.BIN" files. If the data has previously been processed and the file exists it will be loaded instead of the "*.DAT" file. If no '*.BIN' file exists the "*.DAT" file will be loaded.

The only limitation on the "*.DAT" files is that they have the same format as the ASCII output of the Data Transfer program "TSA", outlined in Appendix A. The user must collect the data, translate from the 'TSA' standard format to the ASCII format, and download the file with a communications program (i.e. Procomm) to the INDEXER application.

Once selected, an information window will be displayed informing the user that a specific data file is being loaded. If a '*.MNL' file exists the user is informed, as above, that this file is also being loaded. If no '*.MNL' file exists, all manual information in memory is cleared. If no '*.ANL' file exists, the speed to distance translation and the strength data will be calculated from the force data if the manual information has been loaded or entered.

Once this is completed the program returns to the LOAD DATA MENU.

Manual Data

The user is presented with a window that permits the editing/entering of existing manual data. The user may enter Youngs Modulus, the density of the ice and the orientation and dimensions of the INDEXER plates. This edit screen has a scrolling region of 13 records. Each record contains the ice thickness, the ice flexural,shear and crushing strengths and the fracture toughness for the north and south sides of the ice tank. There are 70 records which correspond to positions in the ice tank.

The user may scroll 10 records at a time by pressing the "PGUP" or "PGDN" keys to indicate the direction of movement. All other edit keys function as previously described.

Pressing the "ESC" key closes the window and moves the user back to the LOAD DATA MENU.

Analyzing

The user may select to view either the flexural, shear, crushing or speed records. The detailed calculation of the strength data from the force data is presented in Appendix C.

a) Strength Plot

The strength data is plotted on the screen using a modified moving average filter with a variable filter width. The default for the filter width is 1 sample. The moving average filter calculates the average value for number of data points defined in the window width and allocates this number to the central position of the window. For example, based on a moving average filter of 5, the value of a specific point, *i*, on the screen is calculated from the mean of *i*-2 to *i*+2.

There are two cursers provided on the screen, one at the start of the strength data (Left Cursor) and one at the end of the plotted data (Right Cursor). The user may move these cursers by using the "CURSOR LEFT" (CRLT) and CURSOR RIGHT" (CRRT) keys. To move faster, the user may press the "CONTROL" (CTRL) and "CURSOR keys. To switch control to the other cursor the user may press the "ENTER" key.

As the user moves the cursor, the strength and distance are displayed on the bottom of the screen.

A list of the active keys for the strength mode are given below:

F1 CLR:	The display is cleared, the cursers positioned to the start and end of the strength data and all the data redrawn.
F2 REDRAW:	The display is cleared, cursers positioned to their original positions and the display redrawn, (maintaining the zoom status).
F3 ZOOM:	The display is cleared and redrawn with the curve enlarged to the segment between the cursers.
F4 FORCE:	The display is cleared and the associated force time history for that strength is displayed.
F5 ANAL:	Calculates and displays the mean, min, max, and standard deviation of the strength data between the two cursers.

F6 FILE:	The ANAL calculations, if any, are appended to the "*.TBL" file.
F7 FLT:	The user is prompted to adjust the filter width, using the cursor keys, the display is then cleared and redrawn using the new filter width.
F8 PRINT:	The display is printed to an EPSON FX compatible printer. The user will hear a beep on the start of output and another beep when the output is finished.
F9 BIAS:	The user is prompted to enter a bias offset which will be added to all data points. If a different value is entered the display is cleared and redrawn using the new offset.
ESC QUIT:	The program returns to the MAIN MENU.
ENTER:	The cursor control will be switched and either an 'L' for left or 'R' for right will appear immediately after the distance indicator.
CRLT, CRRT:	cursor left and right keys move the selected cursor one data point to the left or right.
CTRL+CRLT, CTRL+CRRT:	The "CTRL" key plus "CURSOR" key moves the selected cursor 1/10th of the width of the display in the indicated direction.

b) Force Plot

In the force plot mode, the forces (between the markers) for the specified strength are drawn on the screen. A mark is placed on each peak that is used to calculate the strength.

The user may move the cursers as described above and as the cursor is moved, the strength and distance from the last peak are displayed.

A list of the active keys, for the force mode are given below:

F1 CLR: The display is cleared, the cursers positioned to the start and end of the entire strength array and the display redrawn.

F2 REDRAW: The display is cleared, cursers positioned to their original positions and the display redrawn, (maintaining the zoom status).

F3 ZOOM: The display is cleared and redrawn with the curve enlarged to the segment between the cursers.

F4 STRENGTH: The display is cleared and the user is returned to the STRENGTH mode and the strength curser is drawn.

F5 ADD: A new mark is added to the force plot at the current curser position.

F6 DEL: An existing mark is deleted at the current curser position.

F7 PERCENT: The percentage baseline is drawn above which force peaks may be selected. The user may move the baseline to a new position using the "CRLT" and "CRRT" keys. The baseline is used as a criteria for the maximum points on the force data for strength calculations.

F8 PRINT: The display is printed to an EPSON FX compatible printer. The user will hear a beep at the start of output and another beep when the output is finished.

ENTER: The cursor control will be switched and either an 'L' for left or 'R' for right will appear immediately after the distance indicator.

CRLT, CRRT: Cursor left and right keys move the selected cursor one data point to the left or right.

CTRL+CRLT, CTRL+CRRT: The "CTRL" key plus "CURSOR" key moves the selected cursor 1/10th of the width of the display in the indicated direction.

Save Data

The user is informed which file is being saved. The "*.BIN", "*.MNL", and "*.ANL" files are deleted if they exist, and the new files are created and written to memory. The user is then prompted whether the program should delete the old "*.DAT" file.

Plot Results

The user is presented with a plot configuration screen. This screen contains the plotting device screen (VGA, EGA or CGA) or a printer(EPSON FX compatible) or a plotter(ROLAND DXY-980), a list of up to four graphs may be plotted on one page, 2 lines of 60 characters for a title and 2 lines of 60 characters for a subtitle.

The user may select from the 11 possible plots: Manual Strength - flexural, shearing, crushing; Analyzed Strength - flexural, shearing, crushing; Plate Forces - flexural, shearing, crushing; Ice thickness and INDEXER speed. The user may select up to four of these to be plotted vs. distance on one 8.5" x 11" plot.

Configuration File

The Configuration file permits the user to customize the Indexer program. The file is in ASCII format, called INDEXER.CFG and contains the following information:

- The type of display being used (VGA, EGA or CGA)
- The colours of each screen, and menu.
- The default percentage of mean for peak determination (bending, shearing, crushing).
- The horizontal width of the flexural, shear and crushing plates.
- The angle of the bending and shear plate to the horizontal.
- The angle of the crushing plate to the direction of travel.

Note: The user must use a "text editor" or word processor to change the configuration file. The user should ensure that the modified file is saved in ASCII format.

Appendix A

TSA ASCII Format

The following is a sample of a TSA ASCII format file.

run #(I8), # of channels(I8) (NC), # samples (I8) (NS), Sampling interval(F10.5) (DT)
run title(80A1)
comment1(80A1)
comment2(80A1)
test date(20A1) eg.16-JUL-1989 16:07:35
unknown values (8F10.5)
channel 1 title(32A1)
...
channel NC title(32A1)
calibration constant slope (NC values) (5E15.7)
calibration constant y intercept (NC values) (5E15.7)
data channel 1 to channel N (NS) (13I6)

Actual File

```
      1       4     506   0.02000
PIECE_SIZE_3
ZERO
OK
16-JUL-1987 16:07:35
   0.00000   0.00000   0.00000   0.00000   0.00000   0.00000 0.00000   0.00000
FLEXURAL LOAD (Newtons)
SHEAR LOAD (Newtons)
COMPRESSIVE LOAD (Newtons)
CARRIAGE SPEED (m/s)
 -0.2199345E-01 -0.2191500E-01 -0.1078211E+00  0.4105750E-03
  0.2424570E+01 -0.1740332E+03 -0.2807872E+02  0.9558140E+01
   330    80   -29    16   528   258    24    16   368   217 32    16   488
   121    -8    18   531   209   -45    17   353   217    41 17   488   139
    40    16   483   241   -14    16   408   120   -14    17 520   203   -23
...
    17   387   155    24    17   465   192    42    17   427 233   -13    16
   483   113   -31    16   472   242   -21    17   377   170 26    17   448
   130    59    16   395   209     9    17   553   512   -63 17   450   227
   -14    17   338   155    43    16   449   112    35    17 483   275     9
    17   482   170   -47    17   379   154    27    16
```

Appendix B

Strength Analysis

Flexural Strength

The Flexural strength is calculated from the force time history by selecting all the force peaks that lie within defined constraints. These constraints are;

- The peak must lie above a minimum force, adjustable by the user from the force analysis screen.
- The minimum distance between selected peaks is 80% of the average distance between peaks that lie above the minimum force line.
- The maximum distance between selected peaks is 150% of the average distance between peaks that lie above the minimum force line.

The Flexural Strength is calculated from the following Formula ;

$$FlexuralStrength = \frac{6 \cdot (Force\ at\ Peak) \cdot (Peak\ Separation) \cdot Cos(\angle\ of\ Flexural\ Plate)}{(Ice\ Thickness)^3 \cdot (Horiz.\ Width\ of\ FlexuralPlate)}$$

Shear Analysis

The Shear strength is calculated from the force time history by selecting all the force peaks and minimums that lie within defined constraints. These constraints are;

- The maximum distance between a selected peak and it's associated minimum. This value is equal to a variable set at 0.12 m for speeds less than 0.2 m/sec and 0.025 m for speeds grater than 0.2 m/sec.
- The minimum force difference between a peak and associated minimum is set to 10 N.
- Following the analysis any individual strengths which exceed the average strength by twice the standard deviation are rejected.

The Shear Strength is calculated from the following Formula;

$$ShearStrength = \frac{(Force\ at\ Peak) \cdot Cos(\angle\ of\ Shearing\ Plate)}{(Ice\ Thickness) \cdot (Peak\ MinimumSeparation)}$$

Crushing Analysis

The Crushing strength is calculated from the force time history by selecting all the force peaks and minimums that lie above the minimum force line defined by the user in the force analysis screen.

The Crushing Strength is calculated from the following Formula;

$$\text{Crushing Strength} = \frac{\text{(Force at Peak)}}{\cos(\angle \text{ of Crushing Plate}) \cdot \text{(Ice Thickness)} \cdot \text{(Width of Crushing Plate)}}$$

Appendix C

Configuration File

Configuration file INDEXER.CFG

VGA	screen type CGA, EGA or VGA
3e	main screen colour
16	save screen colour
1f	exit window colour
1f	open window colour
1f	wait window colour
1f	data not saved window colour
1f	info window colour
4f	processing_data_wait_colour
1f	time_wn_colour
1f	main_menu_colour
1f	load_menu_colour
1f	load_indexer_menu_colour
1f	analyze_menu_colour
1f	filelist_colour
1f	file_wn_colour
3e	manual_scrn_colour
3e	plot screen colour
3e	plot menu colour
0f	graphics border colour
0f	graphic boxes and ticks colour
07	graphic data colour
05	graphic strength manual colour
03	graphic cursor colour
01	graphic force marker colour
30.0	fracture percentage
30.0	shearing percentage
30.0	crushing percentage
30.0	bending plate angle (in degrees)
50.0	width of the bending plate (in mm)

30.0	shearing plate angle (in degrees)
30.0	width of the shearing plate (in mm)
30.0	crushing plate angle (in degrees)
20.0	width of the crushing plate (in mm)

Note: The first number or letter, designates the foreground colour and the second number or letter, designates the background colour.

Colour Selection Table

Background	Value	Foreground (Character)	Value
Black	0	Black	0
Blue	1	Blue	1
Green	2	Green	2
Cyan	3	Cyan	3
Red	4	Red	4
Magenta	5	Magenta	5
Brown	6	Brown	6
White	7	White	7
Black Blink	8	Dark Grey	8
Blue Blink	9	Light Blue	9
Green Blink	A	Light Green	A
Cyan Blink	B	Light Cyan	B
Red Blink	C	Light Red	C
Magenta Blink	D	Light Magenta	D
Brown Blink	E	Yellow	E
White Blink	F	Bright White	F